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Commentary

DURING the past month two important events have taken place in the television field. The Alexandra Palace transmitting station has closed down and the London area transmissions are now radiated from Crystal Palace; a delegation of C.C.I.R. members has been to Britain to study the progress we have made towards colour television.

The first event marks the end of an important phase in British television, for it was from Alexandra Palace that the first high definition television system in the world came into regular service on 2 November 1936. The closing down of this station, almost exactly 20 years later must bring nostalgic memories to many who were associated with the television service in its early days. The move to Crystal Palace is not, however, a complete break with tradition, for it was there that some of John Logie Baird's early experiments were carried out. The new transmitting station now constructed, together with its modern equipment, upholds proudly the tradition of British engineering.

The second event, the visit of Study Group XI of the International Radio Consultative Committee (C.C.I.R.), may well influence a future development in the British Television Service; that of colour television. The 100 or so C.C.I.R. delegates from 19 countries have as one of their duties the study of international standards for colour television. The delegates had already seen demonstrations in the U.S.A. and France and, after their London visit they went to Holland for further demonstrations. Later in the year there will be meetings in Warsaw and it is hoped that "what they have seen may open the way for the establishment in the future of international standards for colour television."

It would, from many aspects, be admirable to achieve international standardization, the interchange of programmes would be greatly simplified and international trade in television equipment would be made easier; the achievement of it seems, to say the least, somewhat remote. Although the BBC stress that they are not yet committed to any standard, or system, for colour television, the tests which they have recently been making with the modified N.T.S.C. system, and the lengths to which they intend to carry these tests, seems to indicate that if it is possible to "get by" with a 405 line system and a bandwidth of 5Mc/s, they will do so. Certainly in a country where there are already about six million television receivers in use, there is much to be said for adopting a colour system that will cause as little disruption as possible, but it must be recog-

nized that any decision will be a long term one; once a system is adopted it will be with us for a long time.

As a penalty for being the first country to start a high definition service, we are now saddled with what is, theoretically at least, the lowest standard of definition in use. It is unlikely that other countries will reduce their standards to conform with us and, after all, about the only advantage of a 405 line system is that it requires a smaller bandwidth than, say a 625 line system, and even this factor tends to lose its importance now that the development of Bands III and IV is taking place. For colour television an improved standard of definition and increased bandwidth is an obvious advantage and, even for monochrome, it is doubtful if a 405 line system is adequate now that 21in tubes are being used in production receivers.

In a recent speech, Sir Robert Renwick, President of the Radio and Electronic Component Manufacturers' Federation, made a plea for a 625 line system for colour and said that he thought the BBC made a big mistake in restarting on 405 lines after the war, and that this had a bad effect on our export trade. The blame cannot, however, be laid entirely on the BBC, for it was the recommendation of a Government appointed committee that the pre-war standards should be retained and, in any case, the need for a change was not so evident then as now. A second and, perhaps, a better opportunity for a gradual changeover came when Band III was brought into use last year.

Thus we now have the position where we have one of the lowest theoretical standards of definition and have no National "shop window" for the television equipment we are selling overseas. Further, we have the somewhat anomalous position of a.m. and vertical polarization being used for television, but f.m. and horizontal polarization being preferred for v.h.f. sound broadcasting.

It seems apparent, therefore, that before we progress further and before further large sums of public money are spent on the development of what many consider an incorrect system, a full appraisal of all the technical and economic considerations involved should be made by all the parties concerned, and that their findings should be well publicized so that both the manufacturers and the public will know what to expect in the next ten years or so. Furthermore, any plans made should, if possible, be in accordance with the standards which it is to be hoped will be laid down by the C.C.I.R.

Multivibrator Circuits Using Junction Transistors

By A. E. Jackets*

This article discusses the design and performance of low frequency free-running multivibrator circuits using junction transistors. The principles of operation are discussed; these include the condition for "bottoming", factors determining frequency, and the sharpness of the output waveform. Methods of varying the ratio of the ON to OFF periods are mentioned. G.E.C. EW53 pnp alloy type transistors are used throughout.

MULTIVIBRATOR circuits provide simple means of generating rectangular waveforms. The design of such circuits using thermionic valves is well established. Using point contact transistors it is possible to design a multivibrator type circuit containing only one active element; unfortunately it is not easy to predict the precise waveform without analysing the characteristics of the particular transistor used in some detail. Junction transistors are in many respects similar to thermionic pentodes, and hence multivibrator circuits can be designed using two transistors. There are, however, many important differences between junction transistors and thermionic valves and although the final circuits are similar, there are a number of important differences. It is better when designing the circuits, to approach the problem from an understanding of the mode of operation of the transistors. The analogy with thermionic valves can, however, be useful in deciding the type of circuit to be studied.

Principles of Operation

The basic circuit considered is shown in Fig. 1. Two transistors are connected in the common emitter arrangement. The base of transistor X_1 is coupled via capacitor C_1 to the collector of transistor X_2 and also to the base supply voltage V_B via resistor R_1 ; the collector of X_1 is connected to the supply voltage V_0 via resistor R_{L1} . The base and collector of transistor X_2 are similarly connected.

In a multivibrator a transistor is alternately OFF and ON. In the OFF state, the emitter of the transistor is non-conducting. This is achieved by making the base positive with respect to the emitter. A small collector current termed I_{co} now flows.

The a.c. equivalent circuit of the transistor in the OFF state may be considered as shown in Fig. 2. Since both collector and emitter are biased negatively r_e and r_o are both very high ($\approx 2 \times 10^6 \Omega$) and, since R_L and r_b are generally much smaller than this, the input resistance is approximately $r_o/2$.

In the ON state, the transistor is driven to a high current condition in which the voltage between collector and emitter is very low (about 0.1V). The transistor is said to be just "bottomed" when the emitter current is sufficiently large that any further increase does not significantly alter the collector current. The resistance r_e is now only a few ohms and the input resistance in this state is mainly composed of r_b , the base lead resistance. A typical value of input resistance in this state is 100Ω .

Considering transistor X_1 , the maximum base current that can flow is V_B/R_1 . Also the collector current that flows during the ON period is V_0/R_{L1} . If α_{ob} is taken as the mean value of current gain of X_1 over this range of collector current, the condition for "bottoming" (neglect-

ing I_{co} which is usually very small) is:

$$V_B/R_1 \geq (1/\alpha_{ob}) \cdot (V_0/R_{L1}) \dots \dots \dots (1)$$

Assume that the circuit is such that the transistors can be placed in either the ON or OFF state. To consider the operation assume that X_2 is OFF and X_1 is ON. C_1 now charges towards the potential V_0 through resistor R_{L2} in series with the low input resistance (usually negligible)

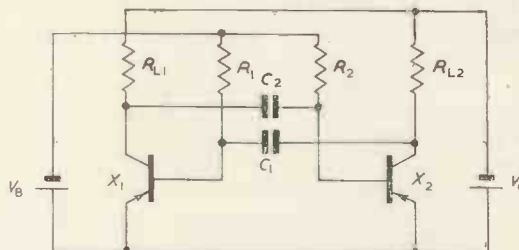


Fig. 1. The circuit of the multivibrator

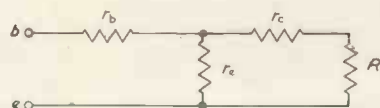


Fig. 2. The a.c. equivalent circuit of the transistor in the "OFF" state

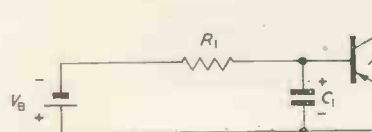


Fig. 3. The equivalent circuit for calculating the period of the multivibrator

of X_1 . The maximum value of the voltage E_1 which can be developed across C_1 in this way is given by the expression:

$$E_1 = V_0 - R_{L2} \cdot I_{co} \dots \dots \dots (2)$$

Assume that X_2 now suddenly starts conducting, the voltage at the collector of X_2 now becomes more positive. Since the voltage across C_1 cannot instantaneously change, the voltage at the base of X_1 also becomes more positive. This tends to cut off X_1 whose collector potential becomes more negative. This negative change in the collector potential of X_1 is applied to the base of X_2 via the capacitor C_2 . This change is amplified by X_2 with the result that its collector potential becomes even more positive. This process results in a rapid regenerative action which is completed when X_1 and X_2 become OFF and ON respectively. At the end of this rapid changeover period, the base of X_1 is at a positive potential equal to E_1 . The input circuit of X_1 may now be represented by the circuit shown in Fig. 3. The input resistance of X_1 is generally very high

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compared with R_1 and it is shown in the Appendix that the time taken for C_1 to discharge to zero is given by:

$$t_1 = R_1 C_1 \ln \left[\frac{V_B + E_1}{V_B} \right] \dots \dots \dots (3)$$

When this occurs, the regenerative action again takes place so that for a symmetrical circuit ($C_1 = C_2 = C$; $R_1 = R_2 = R$; $R_{L1} = R_{L2} = R_L$), the period T of oscillation is given by:

$$T = 2t_1 = 2RC \ln \left[\frac{V_B + E}{V_B} \right] \dots \dots \dots (4)$$

Since $E_1 \approx E_2 = E$.

For an asymmetrical circuit the period of oscillation is:

$$T = t_1 + t_2 = (R_1 C_1 + R_2 C_2) \ln \left[\frac{V_B + E}{V_B} \right] \dots \dots \dots (5)$$

as in this case, also, $E_1 \approx E_2 = E$.

These formulæ assume that the transistors "bottom"; from expression (1) the condition for this is:

$$\alpha_{cb} \geq \frac{V_o \cdot R}{V_B \cdot R_L}$$

The output waveforms obtained from a symmetrical circuit are shown in Figs. 4 and 5.

Using thermionic valves, multivibrators are sometimes designed with the grid resistor returned to earth, rather than the anode supply voltage¹. The corresponding transistor circuit is not satisfactory because this corresponds to $V_B = 0$. Equation (1) is then only satisfied if $\alpha_{cb} \rightarrow \infty$. Since α_{cb} is generally low (of the order of 40), this type of circuit is not satisfactory with transistors.

The Sharpness of the Collector Waveform

A symmetrical circuit is generally used to obtain a waveform having equal ON and OFF periods. There is some advantage in using transistors of equal gain, although this is not essential. The sharpness of the collector waveform is limited by the time taken to charge the capacitor C via the resistor R_L . The higher the value of T/CR_L the sharper will be the waveform. This lack of sharpness relates to the transition of a transistor from ON to OFF; the transition from OFF to ON is generally very rapid. The differences between the two transitions may readily be seen from photographs (b) and (c) in Fig. 5.

From equation (4):

$$\begin{aligned} (T/CR_L) &= (2CR/CR_L) \cdot \ln \left[\frac{V_B + E}{V_B} \right] \\ &= 2(R/R_L) \ln \left[\frac{V_B + E}{V_B} \right] \end{aligned}$$

Usually E is very nearly equal to V_o , the collector supply voltage. ($V_o - E$ is usually about 0.2V).

Hence:

$$(T/CR_L) = 2(R/R_L) \ln (1 + k) \dots \dots \dots (6)$$

where $k = V_o/V_B$.

From equation (1) the maximum value of (R/R_L) , consistent with the transistor "bottoming", is given by:

$$(R/R_L) = \alpha_{cb} \cdot (V_B/V_o) = (\alpha_{cb}/k)$$

This corresponds to a maximum value of (T/CR_L) which becomes:

$$(T/CR_L)_{\max} = 2\alpha_{cb} \cdot \frac{\ln (1 + k)}{k} \dots \dots \dots (7)$$

It is shown in Appendix 2 that $(T/CR_L)_{\max}$ has a maximum value of $2\alpha_{cb}$ when $k = 0$. This means that for transistors of given α_{cb} , the sharpest waveform is obtained

when $V_B \gg V_o$. Since this is not usually a practical condition, the effect of k on the factor $\frac{\ln (1 + k)}{k}$ has been calculated and is shown in Fig. 6. It is seen that the factor is unity when $(V_o/V_B) \rightarrow 0$; 0.91 when $(V_o/V_B) = 0.2$; and 0.69 when $(V_o/V_B) = 1$. This shows that very little advan-



Fig. 4. The base and collector waveforms

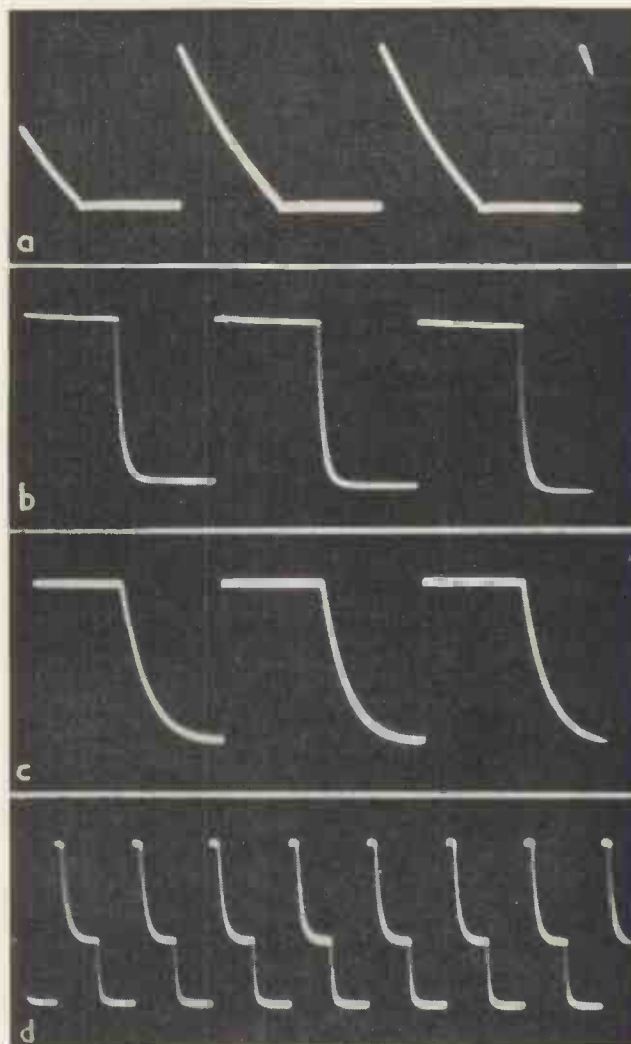


Fig. 5. Waveforms of the circuit of Fig. 7

(a) The base waveform. Frequency 770c/s. (b) The collector waveform. Frequency 770c/s. (c) The collector waveform with R_L increased to $10k\Omega$. Frequency 770c/s. (d) The collector waveform with R_L reduced to $1k\Omega$. The transistor was not bottoming. Frequency 2.1kc/s.

tage is obtained from using extremely low values of k , that is, of (V_o/V_B) . In most practical circuits, it is usual to let k equal unity. It is also seen from equation (7) that the sharpness of the waveform can be improved by using transistors of higher α_{cb} ; it is important, however, to realize

that this improvement is only obtained if (R/R_L) (or (V_o/V_B)) is modified according to equation (1).

It is interesting to note that the value of the capacitor C does not appear in the right-hand side of equation (7).

Methods of Changing Frequency

It is often required to vary the frequency of a symmetrical multivibrator. This may be accomplished by varying C , R , V_B or V_o .

VARIATION OF C

This forms the best method of frequency variation, for the waveform remains constant. This is because the ratio (T/CR_L) , as shown in equation (6), is independent of C . This method has the disadvantage that two capacitors must be altered simultaneously, and the only practical way of doing this is by switching. Therefore the frequency cannot easily be made continuously variable by this method. The

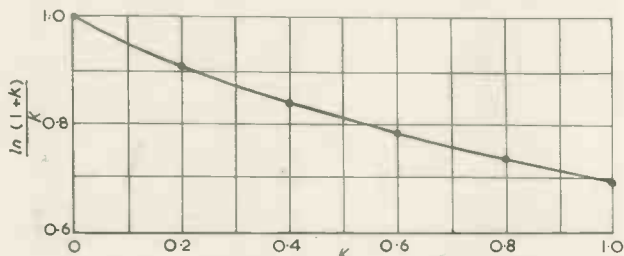


Fig. 6. Graph of $\frac{\ln(1+k)}{k}$ against k

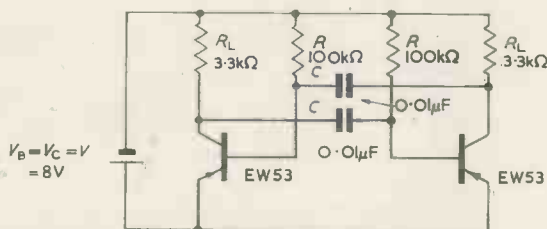


Fig. 7. The multivibrator circuit used for experiment
For each transistor $\alpha_{cb} = 45$

amplitude of the collector output waveform is independent of C .

VARIATION OF R

The chief disadvantage of this method is that the ratio (T/CR_L) is altered, and hence the waveform changes with frequency. Two resistances have to be varied simultaneously and, as twin-ganged potentiometers are obtainable, continuous frequency variation is possible. If R exceeds the value $\alpha_{cb} \cdot (V_B/V_o) \cdot R_L$, the transistor ceases to "bottom" and the waveform changes drastically. This is shown in Fig. 5(d). The output voltage remains constant but the total power consumption varies.

VARIATION OF V_B (V_o MAINTAINED CONSTANT)

This method is convenient in that it may be accomplished with a single potentiometer. However, the waveform changes owing to the variation of the ratio (T/CR_L) . The minimum value of V_B for the transistor to "bottom" may be calculated from equation (1). Again the output voltage remains constant, but the power consumption varies.

VARIATION OF V_o (V_B MAINTAINED CONSTANT)

As the output voltage is almost equal to V_o , the collector voltage varies as well as the frequency. The collector waveform is also altered because the ratio (T/CR_L) is changed.

Some Experimental Results

A symmetrical multivibrator was constructed as shown in Fig. 7. The base and collector waveforms are shown in Figs. 5(a) and (b). Fig. 5(c) shows the effect on the collector waveform when R_L is increased from 3.3 to 10kΩ, and Fig. 5(d) indicates the waveform seen at the collector of a transistor that is not "bottomed" properly.

Each component of the circuit was then individually

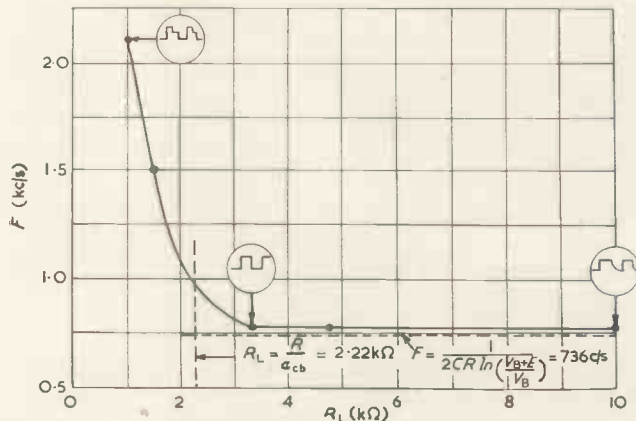


Fig. 8. Graph of frequency against R_L

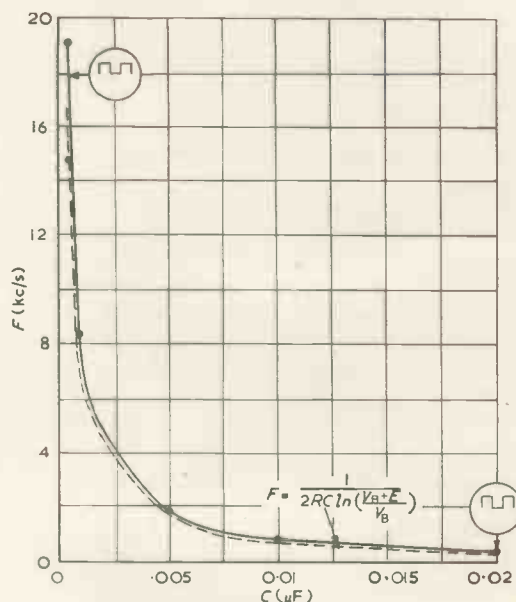


Fig. 9. Graph of frequency against C

varied over a wide range and the frequency plotted against the component value. In all the theoretical curves except Figs. 12 and 13, E has been taken as 7.8V ($V_o = 8V$).

VARIATION OF R_L

Fig. 8 shows the variation of frequency with R_L . The calculated frequency and the lower "bottoming" limit for R_L are shown on the graph, and it will be seen that, when the transistor "bottoms" the frequency is close to the calculated value. The frequency deviates from this and rises rapidly when the transistor ceases to "bottom". The insets show the collector waveform at various values of R_L .

VARIATION OF C

Fig. 9 shows the variation of frequency with C . The dotted curve shows the theoretical frequency variation, assuming $E = 7.8V$. It is seen that the experimental and

theoretical frequencies agree reasonably well. The collector waveform was found to be substantially constant over the wide range of C considered.

VARIATION OF R

Fig. 10 shows the variation of frequency with R . The theoretical frequency variation is shown by the dotted curve. It is noticed from the collector waveform insets that the waveform changes. The maximum value of R for "bottoming" to occur is indicated on the graph.

VARIATION OF V_B , KEEPING V_C CONSTANT AT 8 VOLTS

From the graph in Fig. 11, it is seen that the frequency varies almost linearly with V_B and closely follows the theoretical curve when the transistor is "bottomed". The

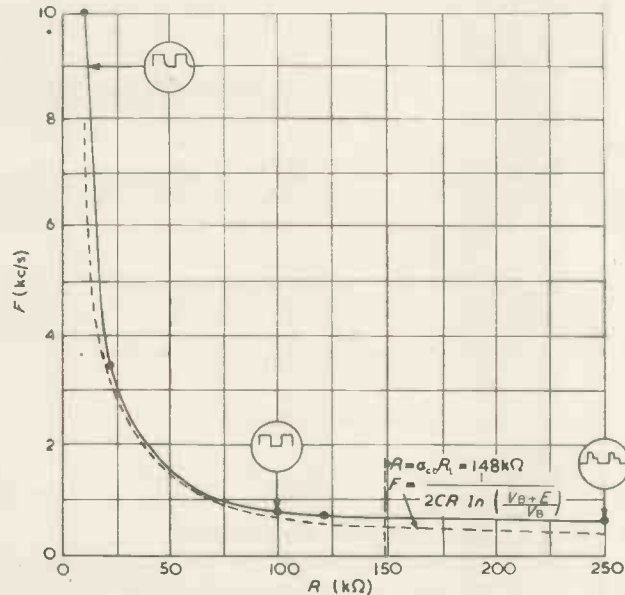


Fig. 10. Graph of frequency against R

minimum voltage for "bottoming" to occur is shown on the graph.

VARIATION OF V_C , KEEPING V_B CONSTANT AT 8 VOLTS

Fig. 12 shows the variation of frequency with V_C . The frequency follows the theoretical curve fairly closely while the transistor remains "bottomed". The "bottoming" limit is shown on the graph. As the peak-to-peak voltage of the collector waveform is almost equal to V_C , the output voltage is changed with V_C . The collector waveform changes are shown in the insets.

VARIATION OF THE SUPPLY VOLTAGE V

The graph in Fig. 13 shows that the frequency is reasonably independent of supply voltage above 6V. This is because, when $V_B = V_C = V$, the period is approximately given by:

$$T = 2CR \ln 2 = 1.39 CR \quad (8)$$

This formula also assumes that $E = V$. However, the error due to this approximation is greatest at low voltages, and this causes a change in frequency as shown in Fig. 13.

Factors in the Design of Some Practical Circuits

SYMMETRICAL MULTIVIBRATORS

When designing a symmetrical multivibrator (and with $V_B = V_C$) it is advantageous to use transistors having equal values of α_{cb} . If this is not convenient, the circuit must be based on the transistor having the lowest value of α_{cb} .

Assuming that the supply voltage is fixed, the first step

is to choose a suitable value of R_L . The resistance of the collector emitter circuit of a transistor in the ON state is typically of the order of 100Ω . R_L should be large compared with this value for predictable performance. If R_L is made too high, difficulties may arise owing to the fact that I_{co} may become comparable with the base current in

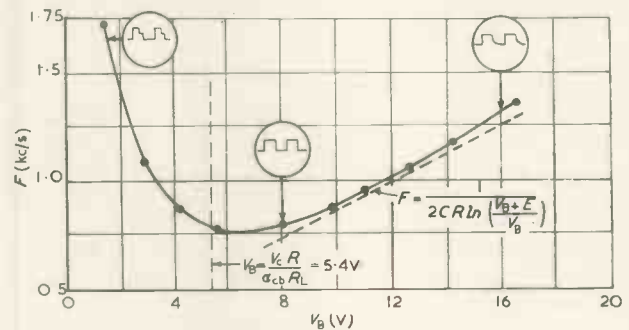


Fig. 11. Graph of frequency against V_B

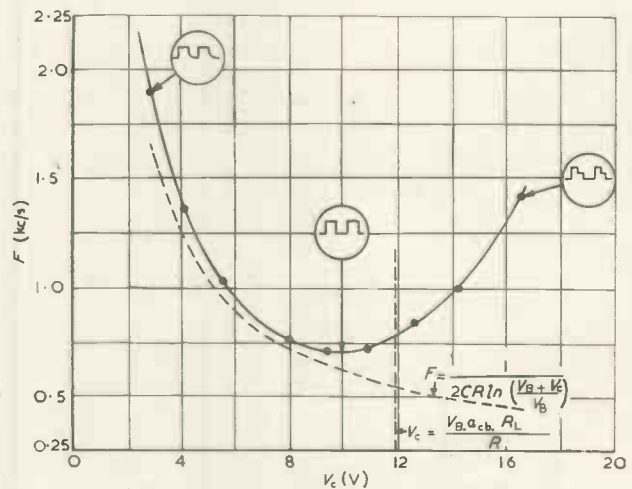


Fig. 12. Graph of frequency against V_C

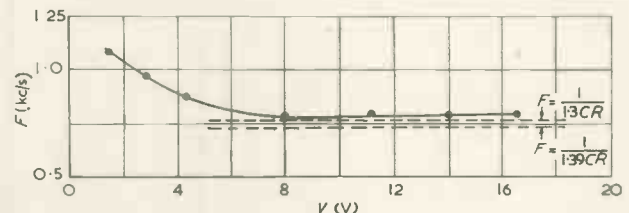


Fig. 13. Graph of frequency against supply voltage (V)

the ON state. For a given value of R_L , it is seen from equations (1) and (6) that, if α_{cb} is increased, then R must be increased proportionately in order to ensure a sharp collector waveform. The higher the value of R , however, the more dependent is the operation on I_{co} and hence on the temperature. In the circuits discussed here, values of R_L between 1 and $10k\Omega$ were found satisfactory. The power consumption of the circuit as well as the power developed in R_L , is determined by the value of R_L that is chosen.

Having chosen R_L , and knowing the lowest value of α_{cb} to be encountered, R is chosen from the formula given in equation (1). This value of R is the maximum value that can be used consistent with the condition that the transistors must just "bottom". In practice, a value of R about

20 per cent lower than this is used in order to ensure a satisfactory degree of "bottoming".

The value of C is chosen from equation (4) to determine the frequency of operation. An approximate value may be calculated from equation (8), which is simpler than equation (4). This latter expression will give a value of frequency that is slightly low (see Fig. 13). In practice, a better approximation is given by the expression:

$$T = 1.3 CR \dots\dots\dots (9)$$

ASYMMETRICAL MULTIVIBRATORS

The design is similar to that of the symmetrical multivibrator, except that the two OFF periods are calculated separately. Where the circuits have to be designed to operate with any transistor having a value of α_{cb} greater than some minimum value, the values of R_L and R are selected as before and are equal for the two transistors. C_1 and C_2 are then chosen from equation (3), which may be approximated to:

$$t_1 = 0.69 C_1 R_1 \dots\dots\dots (10)$$

In practice, a better approximation is given by:

$$t_1 = 0.65 C_1 R_1 \dots\dots\dots (11)$$

If, however, these circuits are to be designed to operate with two specific transistors, some improvement in waveform sharpness may be obtained by selecting optimum values of R for each transistor independently. This method of design is satisfactory up to ON/OFF ratios of about 1:5.

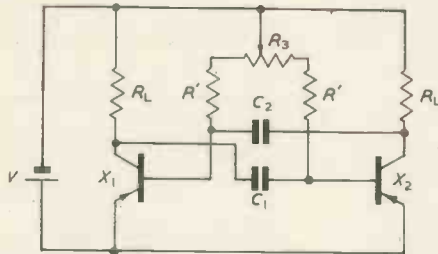


Fig. 14. The circuit to alter the "ON"/"OFF" ratio while maintaining the frequency reasonably constant

A Simple Method for Varying the "ON"/"OFF" Ratio Without Changing the Multivibrator Frequency

If $C_1 = C_2 = C$, equation (5) becomes:

$$T = t_1 + t_2 = (R_1 + R_2) C \ln \left[\frac{V_B + E}{V_B} \right] \dots\dots (12)$$

Thus if R_1 and R_2 are varied, keeping $(R_1 + R_2)$ constant, the ON/OFF ratio (i.e. the ratio of t_1 to t_2) may be varied, but at the same time keeping T (and hence the frequency) constant. R_1 and R_2 must both be kept lower than the maximum value required for the transistor to "bottom" (equation 1). This means that the waveform is not as sharp as it might be, and also that it varies as R_1 and R_2 are varied. In practice it is also found that small changes in frequency do occur. The chief virtue of this circuit is that R_1 and R_2 can be easily varied by making the junction of R_1 and R_2 the slider of a potentiometer connected between the base electrodes of the two transistors. The arrangement is shown in Fig. 14. It is desirable also to connect two fixed resistors of value R' in series with the base lead. The sum of $R' + R_3$, where R_3 is the total resistance of the potentiometer, must be less than the maximum value of R determined from equation (1).

Frequency Limitations

Reasonable agreement between calculated and practical performance is found at frequencies up to 10kc/s. Above

10kc/s the frequency is found to exceed the calculated value (assuming $E \approx V_c$), because E decreases as the frequency is increased. When the measured value of E (see Fig. 4) is used better agreement is found. The reasons for these deviations are not fully understood.

Conclusions

Conventional RC coupled multivibrator circuits can be designed using junction transistors. These give predictable performance up to a frequency of at least 10kc/s. They can be operated from a low supply voltage and can be designed so that the frequency is substantially independent of changes in this voltage.

In order that a good waveform be obtained, it is necessary that the transistor in the ON state should be fully "bottomed". It is also necessary that the circuit should be designed so that the transition from ON to OFF occurs as rapidly as possible.

The repetition frequency can be varied in a number of ways. One of these, namely the variation of the coupling capacitors, has a minimum effect on the collector waveform. Continuous variation of frequency can best be obtained by varying the potential to which the base resistors are returned; this, however, gives rise to variation in waveform.

Transistors having low values of current gain may be used. However, a sharper transition from ON to OFF can be obtained using high gain transistors in a suitably designed circuit.

APPENDICES

(1) THE RELATIONSHIP $t_1 = C_1 R_1 \ln \left[\frac{V_B + E_1}{V_B} \right]$

In Fig. 1, when transistor X_2 conducts, C_1 (which is charged to E_1 volts) is switched across the input of transistor X_1 , as shown in Fig. 3. X_1 will be held OFF until the voltage across C_1 decays from E_1 volts to zero volts. The input resistance of X_1 is usually high compared with R_1 , and may be neglected.

Let i equal the current in the circuit after a time t .

Let v equal the voltage across C_1 after a time t .

Then $V_B + iR_1 + v = 0$

But:

$$i = C_1 (dv/dt)$$

$$-(dt/C_1 R_1) = \frac{dv}{(V_B + v)}$$

Integrating:

$$-(t/C_1 R_1) = \ln (V_B + v) + K$$

But when $t = 0, v = E_1,$

$$\therefore K = - \ln (V_B + E_1)$$

Hence:

$$t = C_1 R_1 \ln \left[\frac{V_B + E_1}{V_B + v} \right]$$

Also when $t = t_1, v = 0$

Therefore:

$$t_1 = C_1 R_1 \ln \left[\frac{V_B + E_1}{V_B} \right]$$

(2) THE MAXIMUM VALUE OF $(T/CR_L)_{max}$

$$(T/CR_L)_{max} = 2\alpha_{cb} \frac{\ln(1+k)}{k} \dots\dots\dots (7)$$

For a given transistor the only changeable part of the right-hand side of equation (7) is the factor $\frac{\ln(1+k)}{k}$

$$\text{Let } y = \frac{\ln(1+k)}{k}$$

$$dy/dk = \frac{k[1/(1+k)] - \ln(1+k)}{k^2}$$

so dy/dk is zero when:

$$\frac{k}{1+k} = \ln(1+k)$$

i.e. when $k = 0$.

The maximum value of y is therefore:

$$k \rightarrow 0 \frac{\ln(1+k)}{k}$$

By L'Hospital's rule²

$$k \rightarrow 0 \frac{\ln(1+k)}{k} = k \rightarrow 0 \frac{1}{(1+k)/1} = 1$$

The maximum value of $\frac{\ln(1+k)}{k}$ is therefore 1.

So the maximum value of $(T/CR_L)_{\max}$ is $2\alpha_{ob}$.

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2. PIPES, L. A. Mathematics for Engineers and Physicists, p. 31. (McGraw-Hill, 1946)

The BBC's New London Television Station

On March 28 the BBC's new London television station at Crystal Palace came into service. The new station uses the same frequencies as did Alexandra Palace, but a vestigial upper sideband characteristic has been adopted for the vision transmissions as at all post-war BBC television stations.

The transmitter building itself is sunk into a terrace so as not to interfere with the amenities of the grounds.

The main transmitter hall contains two vision and two sound transmitters.

Each vision transmitter has a peak white output power of 15kW and is grid modulated in the final stage in which the use of a pair of high-power type CR192 tetrodes is noteworthy. The high gain of these valves allows the use of receiving type valves in the modulator and also reduces the number of r.f. amplifying stages required. Another interesting feature of the final stage is the triple tuned output circuit. For reliability, metal rectifiers are used for the 6kV anode supply.

Black level feedback ensures that the black level in the radiated vision signal will remain constant to within 2 per cent of the correct value. The centre frequency of the band-pass characteristic of the transmitter output circuit is offset from 45Mc/s to 44Mc/s to take advantage of the narrower bandwidth and hence the higher output power permitted by the vestigial sideband characteristic of the transmission. The transmitter tuned circuits are not relied on for any of the shaping of the unwanted upper sideband, as this is done by the two vestigial upper sideband filters into which the outputs of the two vision transmitters are fed.

The sound transmitters are class-B modulated in the final stage and are rated at $4\frac{1}{2}$ kW carrier output, but will operate at $3\frac{3}{4}$ kW to preserve the standard ratio of 4 to 1 between peak white vision and sound carrier power. The design is straightforward, but the use of 20dB of negative feedback over the a.f. chain keeps the distortion at less than 1 per cent at 95 per cent modulation.

Water-cooled test loads are provided for each transmitter. Thus any transmitter may be tested while the remaining transmitters are still carrying programme.

The phases of the pairs of vision and sound transmitters are compared at similar points near the inputs to the combining filters and monitored and adjusted to the correct values by the r.f. phasing equipment in the control room. It is found that very little phase drift occurs after the first ten minutes after switching on.

The transmitter control room is situated at the end of the transmitter hall which can be viewed through sliding glass windows. From here the engineer on duty can see all the transmitters under his control. The control room contains, in addition to the main transmitter control desk, the duplicate drive and phasing equipment for the transmitters, the vision and sound programme input equipment, together with distribution amplifiers and a transparency scanner for the local generation of captions and test cards. Magnetic tape sound reproducers are

also installed to provide locally generated announcements in case of emergency.

The four transmitters can be started from cold, and shut down, from the control desk. Two picture monitors and a waveform monitor are mounted on the sloping front of the desk. These normally display the input and output pictures and the output waveform, but they can be switched, by push-button operated relays, to other points in the transmitter chain.

At the top of the control desk is an illuminated mimic diagram showing the arrangement of the transmitter and aerial feeder coaxial switches.

A key switch panel is provided for selecting the input to be fed to the sound and vision transmitters; this may be the television programme, one of a variety of test patterns, or the output of the local caption scanner.

A peak programme meter and two percentage modulation meters are provided to enable the sound signal to be checked.

The outputs of the four transmitters are combined in the following way. The output from one sound transmitter is combined with the output of one vision transmitter. The outputs of the other sound and vision transmitters are also combined.

The feeders from the combining units are routed to the base of the aerial tower via a feeder switching room on an upper floor in which eight coaxial switches are provided to enable the transmitters and feeders to be interchanged in all possible combinations in the event of faults developing in the transmitters, feeders or aerial system. Under normal conditions the output of each combining unit is connected to one-half of the aerial system.

The temporary aerial to be used initially consists of six dipoles mounted in two tiers on the three corners of the 250ft triangular stayed mast.

The partly completed permanent tower has at present a height of approximately 440ft, but in its final form it will be 640ft high. Preparations are in hand for erecting—by about July of this year—a four-stack temporary aerial near the top of the tower as it is at present. This will increase the effective height of the aerial from 200ft to about 400ft and at the same time enable the effective radiated power to be increased from 60kW to 120kW.

Later, in 1957 when the tower is completed, a further four stacks of dipoles will be erected above the 440ft level and the e.r.p. will be further increased to 200kW. Above the Band I aerial there will be space for two high gain Band III transmitting aeriels.

Test equipment is installed for carrying out routine performance measurements on the vision circuits to Broadcasting House, and on the vision and sound transmitters and feeder system.

The vision and sound transmitters, drive equipment, combining units and some of the other ancillary equipment has been supplied by Marconi's Wireless Telegraph Co. Ltd.

A Digital Differential Simultaneous Bi-directional Counting using a Dekatron

By W. H. P. Leslie*, B.Sc., A.M.I.E.E.

A new circuit is described using a Dekatron to indicate the running difference in count between two independent pulse trains. It is applied to indicate frequency differences—to generate difference frequency signals without tuned circuits—to control frequency or speed relative to a master signal which may originate from a quartz oscillator, wide range oscillator, or from a shaft whose speed has to be copied.

DURING the development of a precision speed control system¹ the electrical equivalent of a differential gear unit was required. The system was digital in nature, an indication of the difference in pulse repetition rate of a standard and a controlled signal being desired. A bi-directional uniselector switch was first used, following which the Dekatron circuits described below were developed to allow faster counting rates.

Normal Dekatron Operation

To describe the operation of the bi-directional counter it is necessary to review the normal operation of a "double-pulse" Dekatron (a more complete description can be obtained in the valve-maker's booklet²). The valve used, a GS10B, has a maximum counting speed of 5kc/s, although there has recently appeared the GS10C selector tube Dekatron suitable for 20kc/s.

In Fig. 1 the signal to be counted is applied to the grid of valve V_1 , having been formed into positive pulses of $60\mu\text{sec}$ duration. The large $60\mu\text{sec}$ negative pulses generated at V_1 anode are applied to two potential dividers R_1R_2 and R_3C_3 . R_1R_2 produces a similar rectangular pulse of half amplitude, while R_3C_3 produces an integrated waveform. The time-constant R_3C_3 is chosen so that the sloping front of the pulse has passed half amplitude at the end of the pulse; thereafter the waveform returns slowly positive.

The Dekatron contains an anode and ten counting cathodes. Between each pair of cathodes are two transfer electrodes T_1 and T_2 . All T_1 electrodes are connected to one input terminal and all T_2 electrodes to another. Assume that the glow is on cathode "2" in Fig. 1, a signal pulse first makes itself known by a negative pulse on the ten T_1 electrodes. The particular T_1 nearest to the conducting cathode "2" strikes most easily since it is partially in the ionized gas around "2". After T_1 has started glowing it carries the anode potential down due to the fixed potential difference between the electrodes of a glow discharge. The reduced voltage between the anode and cathode "2" extinguishes the discharge that existed there. At the end of the transfer pulse T_1 returns positive and the glow transfers to the adjacent T_2 electrode which is being held negative by the integrated transfer pulse. As T_2 returns to its positive voltage the glow transfers to the nearest cathode which is now "3". In a normal counter the process repeats and the glow progresses round the tube in a clockwise direction in response to drive pulses. When anti-clockwise progression is required it is only necessary to connect the direct pulses (via R_1R_2) to T_2 and the integrated pulses to T_1 .

Bi-Directional Drive

Fig. 2 shows how two sets of drive pulses can be

supplied to valves V_1 and V_2 in order to produce clockwise rotation for V_1 pulses and anti-clockwise for V_2 pulses. When pulse trains are applied simultaneously to V_1 and V_2 the glow moves at a rate indicating the difference* in

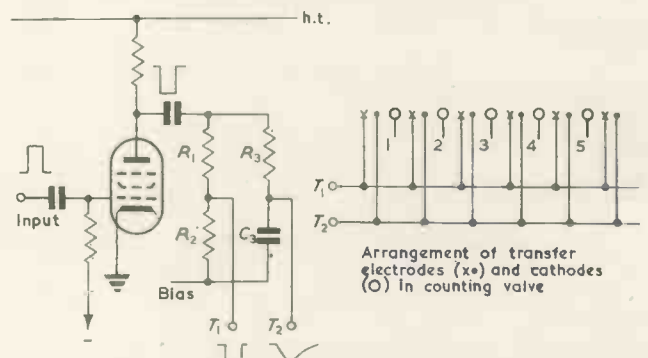


Fig. 1. Essential features of valve manufacturer's circuit

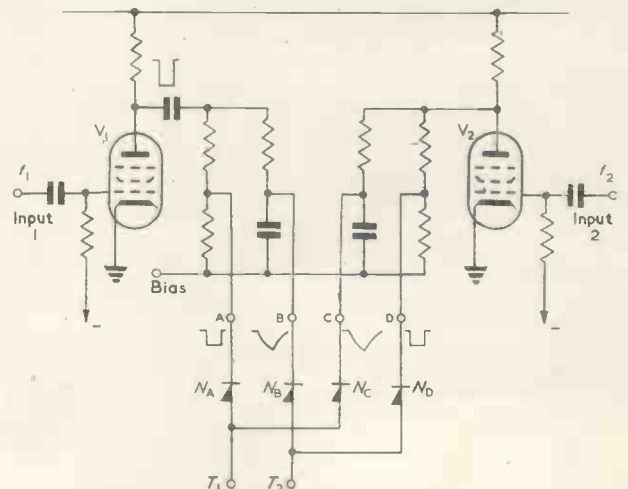


Fig. 2. Bi-directional counter drive circuit

frequency. To understand why the counter performs without error it is necessary to consider three cases:—

- (1) Pulses at V_1 and V_2 occur interleaved but not at the same time; the glow advances for each V_1 pulse and returns for each V_2 pulse so that the net movement indicates the difference in count.
- (2) Pulses arrive at V_1 and V_2 at the same instant. Thus pulses appear at transfer electrodes T_1 and T_2 at the same time and the glow (at cathode "2" say)

* Shortly after the circuit was evolved for this purpose by the author, it was published independently³ by the valve manufacturer but the latter only offered it for alternative clockwise or anticlockwise counting. They made no mention that it would operate for simultaneous counting.

* Mechanical Engineering Research Laboratory, D.S.I.R.

spreads to either or both T_1 and T_2 electrodes adjacent to "2". At the end of the direct pulses both T_1 and T_2 are held negative by the two integrated pulses so that there is no glow movement. As the integrated pulses return positive the cathode nearest to the glow is "2" so the glow returns there. The net effect is no count as it should be.

- (3) A pulse may reach V_2 during a V_1 pulse. The glow moves to T_1 first; when the direct pulse at T_1 finishes, the voltage does not return completely positive owing to the beginning of the integrated pulse from V_2 ; if the glow transfers to T_2 it returns again to T_1 after the direct V_2 pulse has ended. When the integrated V_2 pulse on T_1 ends the pulse returns to the cathode from which it started. The net effect of no count is correct.

Experimentally it is found that correct counting is obtained in all circumstances providing the pulses generated by V_1 and V_2 are of similar width. It is possible to apply two pulse trains of 2kc/s with a frequency difference of as little as 1 cycle in 10 seconds so that the glow moves slowly round the tube. Such a condition provides an effective method of setting one pulse width having set the other pulse train to give optimum counting speed.

Adding

Although the circuit subtracts without error it will not add correctly since coincident pulses from the two trains (with suitable cross connexion to T_1 and T_2) would only produce one count. To overcome this difficulty it would be necessary to delay any pulse which arrived during the active time of another pulse.

Output Signal Circuit

When the counter is to be used to generate an output it is necessary to make suitable cathode connexions. Figs. 3(a) and 3(b) show convenient methods of generating stepped approximations to sinusoidal and square waves respectively at $(f_1 - f_2)/10 \text{ c/s}$ where $f_1 \text{ c/s}$ is the frequency of the signal applied to V_1 and $f_2 \text{ c/s}$ that applied to V_2 . Fig. 4(a) shows the voltage produced when $f_1 = 1000 \text{ c/s}$ and $f_2 = 990 \text{ c/s}$. Fig. 4(b) shows the effect of adding a single smoothing capacitor of $0.05 \mu\text{F}$. Similarity Figs. 5(a) and 5(b) show the corresponding square waves.

Such an output can be applied to the generation of low audio frequencies of high stability. For example a range of 48 to 52 c/s may be required as a master frequency for an alternator control or for calibrating a power frequency meter. In this case f_1 could be made 5350 c/s from a quartz crystal or tuning fork. f_2 could be made variable between 150 and 550 c/s from a stable RC oscillator which can be purchased with an accuracy of ± 0.25 per cent and a half-hour stability of 0.025 per cent. The output would then range from 520 to 480 c/s and after division by ten, using a normal Dekatron stage, would give 52 to 48 c/s with an accuracy of 0.025 per cent and a half-hour stability of 25 parts in 10^6 , adequate for many purposes. The RC oscillator can be checked accurately at 535 c/s by dividing the quartz crystal frequency by ten using the Dekatron stage and comparing with the nominal 535 c/s from the RC oscillator visually at the differential counter.

Limitations

The limitations of this method should be noted. It is only possible to get improved accuracy of the variable oscillator by restricting its frequencies relative to the fixed oscillator of better accuracy. This limitation is shared with other frequency mixers. The other limitation is due to the

digital nature of the process. Consider a particular case when $f_1 = 25f_2$. In the absence of f_2 it takes 10 counts from f_1 to obtain one circulation from the glow; when an f_2 count subtracts one count the circulator requires 11 counts from f_1 . Following this process step by step for the case considered it is found that the time for each cycle (circulation of the glow) in terms of cycles of f_1 is:

10, a, 10, 11, 10, 11, 10, 10, 11, 10, 10, 11, a, 10, etc.

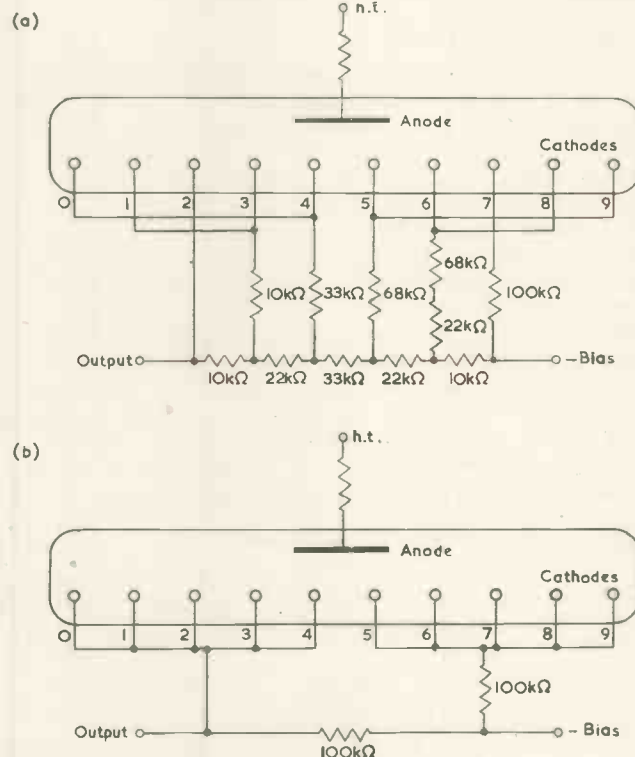


Fig. 3(a). Sinusoidal output circuit
(b). Square wave output circuit

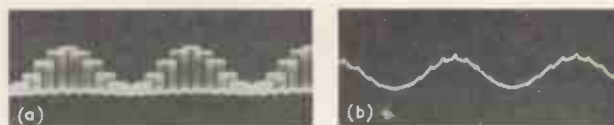


Fig. 4(a). Sine wave circuit—no smoothing
(b). Sine wave circuit— $0.05 \mu\text{F}$ smoothing



Fig. 5(a). Square wave circuit—no smoothing
(b). Square wave—smoothing $0.05 \mu\text{F}$

where the times between "a a" repeat. Thus individual cycles vary in time by 10 per cent. The average length is $(125/12)$ cycles so that the averaged frequency is $(24/250)f_1$. This is exact as $f_1 - f_2 = (24/25)f_1$ and the differential divides the frequency by ten. The cycle to cycle error is reduced to 1 per cent if the output of the differential is divided by ten in a normal Dekatron divider giving cycle times in terms of f_1 cycles of:

b, 104, 104, 104, 105, 104, 104, b, 104, etc.

and repeating between "b b". The average time is $(625/6)$ cycles of f_1 so that the averaged frequency is $(24/2500)f_1$ an exact result.

This limitation has been discussed in some detail since it can easily be overlooked. For many applications where the frequency is averaged by inertia or smoothing circuits the divided output, as used to obtain the 48 to 52c/s signal above, will be acceptable. The effect is at its worst when there is one f_2 cycle for ten or more f_1 cycles. When f_1 and f_2 are nearly equal so that one output cycle takes say 1 000 f_1 cycles and 990 f_2 cycles the smoothed output cycles cannot vary by more than 0.1 per cent.

Output Control Circuit

It is when the circuit is used in a frequency or speed controller that it is most useful. In this application f_1 is a standard frequency, f_2 is the frequency to be controlled. Any error results in rotation of the glow in the tube. By disconnection of cathode "0" so that the glow cannot rest on it the rotation is prevented at "1" and "9". Thus if f_2 is low in frequency the glow rests on "9" and if it is high it rests on "1". This is the effect obtained from a mechanical differential driving a pointer through a friction clutch, the rotation of the pointer being limited by stops. The position of the glow can be detected electrically by inserting resistors in the cathode circuits as shown in Fig. 6. When the glow is on cathode "9" the cathode current goes straight to negative bias producing no output voltage. As the glow moves along to 8, 7, 6 etc. the cathode current passes through more of the chain R_A to R_H producing progressively more positive voltages at the output.

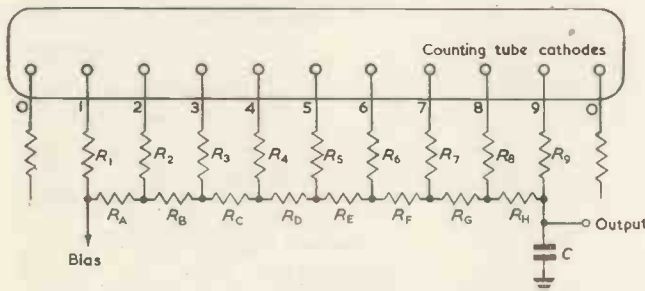


Fig. 6. Preferred output circuit

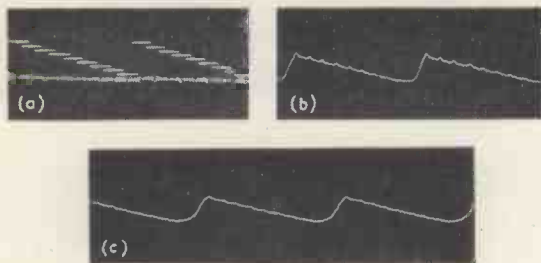


Fig. 7. Stepped output 980 and 1 000c/s applied

- (a). Staircase output—no smoothing
- (b). Staircase output— $0.05\mu\text{F}$
- (c). Staircase output— $0.25\mu\text{F}$

With "0" connected to earth for testing, the network produces the stepped output shown in Fig. 7(a). The addition of a $0.05\mu\text{F}$ smoothing capacitor (C in Fig. 6) produces the output in Fig. 7(b). The output voltage can be taken to control the frequency or speed, raising f_2 when towards "9" and lowering it when near "1". The glow then settles on the step which causes equality between f_1 and f_2 . It would appear unfortunate that only 9 steps of voltage are available but the actual control process gives infinite variation in output. The f_1 and f_2 pulses interleave so that each f_1 pulse increases the count say from "4" to "5"

and each f_2 pulse decreases it from "5" to "4". The glow appears to rest on the two cathodes and if more output voltage becomes necessary (to maintain speed due to increased load for example) the relative phase of the two signals will alter to give a longer dwell on "5" and a

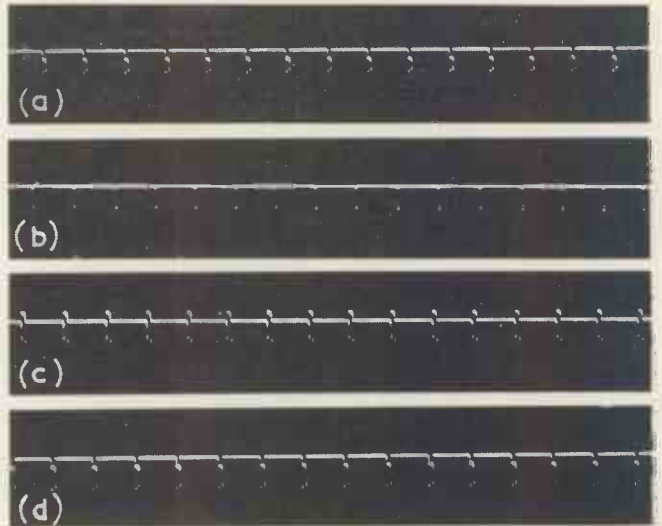


Fig. 8. Output variation between steps both frequencies 100c/s, phase varied

- Fig. (a). On cathodes 2 and mainly 3
- (b). On cathode 3
- (c). On cathodes 4 and mainly 3
- (d). On cathodes 3 and mainly 4

shorter dwell on "4" increasing the average voltage. Fig. 8 illustrates the process: 8(a) shows a steady condition giving a voltage on cathode 2 and mainly on cathode 3; 8(b) shows the glow on cathode 3 (drive pulses exactly in phase); 8(c) shows the glow mainly on cathode 3 with brief excursions to cathode 4 so that the average voltage is just greater than corresponds to cathode 3 alone; 8(d) shows the glow still on cathode 3 but now mainly on cathode 4.

Conclusion

It can be seen from the above discussion that the electronic differential possesses the desirable combination of coarse control (speed grossly high or low) with fine control (phase locking). Most existing speed control systems have considerable difficulty in maintaining the accuracy of the coarse control over a range of speeds so that it brings the speed within reach of the fine controller. A motor speed control utilizing this differential together with other pulse counters was demonstrated at the Physical Society Exhibition³ in April, 1955, maintaining motor speeds from 200 to 4 500 rev/min locked to a 10kc/s frequency standard.

Further Applications

Further development with the differential will be aimed at obtaining higher operating frequencies with new types of counting tube and reliability by using improved circuits and valves, although experience so far has been promising. Among other applications the circuit lends itself to the digital control of machine tools since the differential basically compares positions of shafts or slides rather than speed. If used in tool control it might be necessary to extend the differential by one or more reversible decades in order to store the count until the tool obeyed the command. This can be done by using the same type of drive circuit for each stage and handing on the count as the glow leaves cathode 9 for transfer electrode T_1 and subtracting a count as it leaves T_1 for 9. When first envisaged it was thought that two pentodes would have to be employed

to recognize (using suitable integrating circuits to their suppressor grids) these two states. Recently a new Dekatron has been described⁴ with the transfer electrodes between 9 and 0 separately brought out. If this tube becomes available in the form of a selector tube rather than a counter it will simplify the construction of such a simultaneous reversible bi-directional multi-decade counter. It should be noted that reference 4 deals with the special case of reversible counting of mechanically derived impulses where the two trains of transfer pulses can be obtained with the correct phase automatically: only one instruction is given to the counter at any one instant. A hard valve counter for this purpose has also been described⁵.

Acknowledgments

The author acknowledges the able help of Mr. J. J. Hunter and Mr. A. Russell who constructed the various circuits and prepared the figures. The work described was

carried out in the Fluids Division of the Mechanical Engineering Research Laboratory and is published by permission of the Director of the Laboratory.

A patent application has been filed in connexion with the work carried out at the Mechanical Engineering Research Laboratory. The rights have been assigned to the National Research Development Corporation, 1 Tilney Street, London, W.1, who will be pleased to hear from anyone interested in making or using the digital differential for precise speed control or any other purpose.

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A Horizontal Boring Machine with Automatic Co-ordinate Setting

SOME two years ago the British Thomson-Houston Co. Ltd. commenced the development of automatic co-ordinate setting for boring machines and the first commercial installation was completed recently for the Leicester factory of the British United Shoe Machinery Co. Ltd. The work has been carried out in co-operation with H. W. Kearns & Co. Ltd. the automatic controls being applied to a Kearns No. 0 Planer Table Type Horizontal Boring Machine.

Essentially the co-ordinate setter comprises servo-mechanisms operating the horizontal and vertical slides of the machine which have traverses of 57in and 42in respectively. The slides can be set to any position by setting up the co-ordinates on dials, which can be seen on the face of the control desk in Figs. 1 and 2. Six dials and clearly displayed figures are provided for each of the two ordinates, to set up any required displacement from a predetermined datum.

The "dial-in" feature is appropriate to very short run production and tool-room class of work generally.

For longer runs the slides can be set up by a card reader on the operator's control desk. One punched card per hole centre has been adopted, which enables operator instructions to be added where appropriate, thus a deck of cards must be prepared per workpiece.

The blue-print (which may not be required on the factory floor so far as the boring operations are concerned) will show dimensions with respect to two datum lines convenient to the particular workpiece. To simplify setting up procedures, the co-ordinate setter includes means for changing quickly the datum of measurement for each traverse.

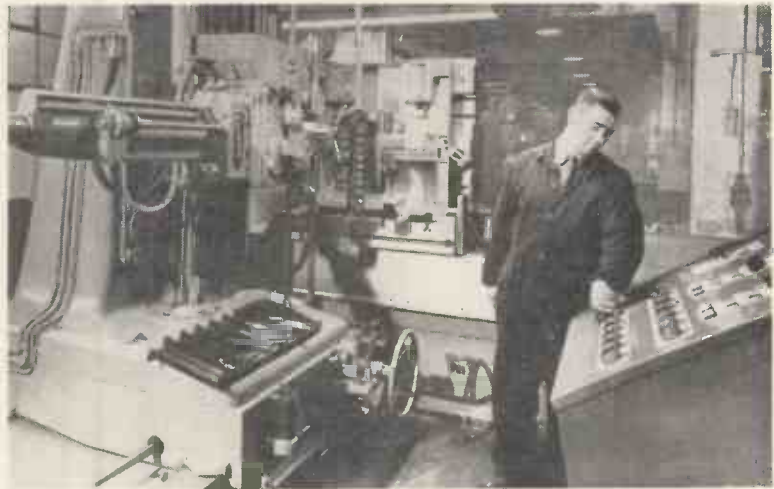


Fig. 1. The boring machine and control unit

The machine tool is basically a normal Kearns horizontal borer with the addition of the power servos already mentioned and a built-in measuring system for automatic control.

Principles of Operation

The card reader unit serves to shift the hand setting dials, thereby giving a check, if necessary, on the accuracy of card reading. Identical servo-systems are used for both traverses and it is therefore sufficient to describe operation from the dial shafts on the operator's desk, to the control of one motion.

Referring to Fig. 3, the electrical measuring system on the machine tool table comprises a rigid measuring bar accurately divided into one inch units by holes spaced 1in apart along its length. An electromagnetic sensing head, mounted on the bed of the machine tool co-operates with the bar and provides an electrical misalignment signal to the control system. The electromagnetic unit can be shifted by a micrometer screw and an accurate instrument servo through any displacement up to one inch.

Thus the measuring bar may be regarded as providing accurate measurement of the integral inches part of a required co-ordinate shift, while the decimal part is accommodated by accurately controlled shift of the sensing head.

In more detail the controlling action is as follows,

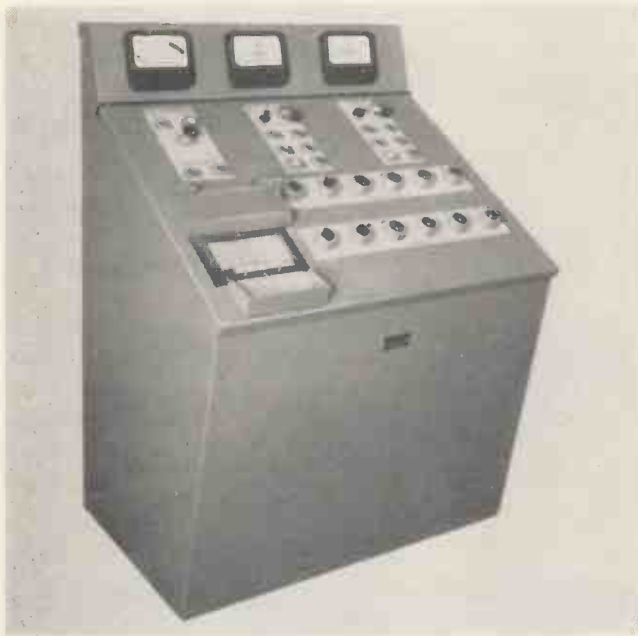


Fig. 2. The control desk

screw shift the electromagnetic unit through the required decimal dimension.

The integral part of the desired co-ordinate (with a contribution from the decimal part) gives a rotation of synchro S_1 which is interconnected with synchro T_1 geared to the leadscrew. A misalignment signal from S_1-T_1 controls servo-amplifier C and via the motor M_2 brings the table to within about 0.2in of the desired position, the traverse speed being maintained at about 120in/min until the last inch or so of travel is reached, after which the speed is progressively reduced.

Control of M_2 is now transferred (via servo amplifier B) to the electromagnetic head. The control signal from the latter drives M_2 until the poles of the magnetic head are aligned opposite the nearest hole in the bar, under which conditions the error signal from the magnetic head becomes zero.

During the approach to alignment under the control of the electromagnetic head, a temporary misalignment signal is injected into amplifier B , so that the table travels to a "false alignment" position, approximately 0.020in from the true alignment. The temporary signal is then automatically removed and thus the final approach to alignment is always from the same direction. The error signal from the magnetic head is proportional to displacement

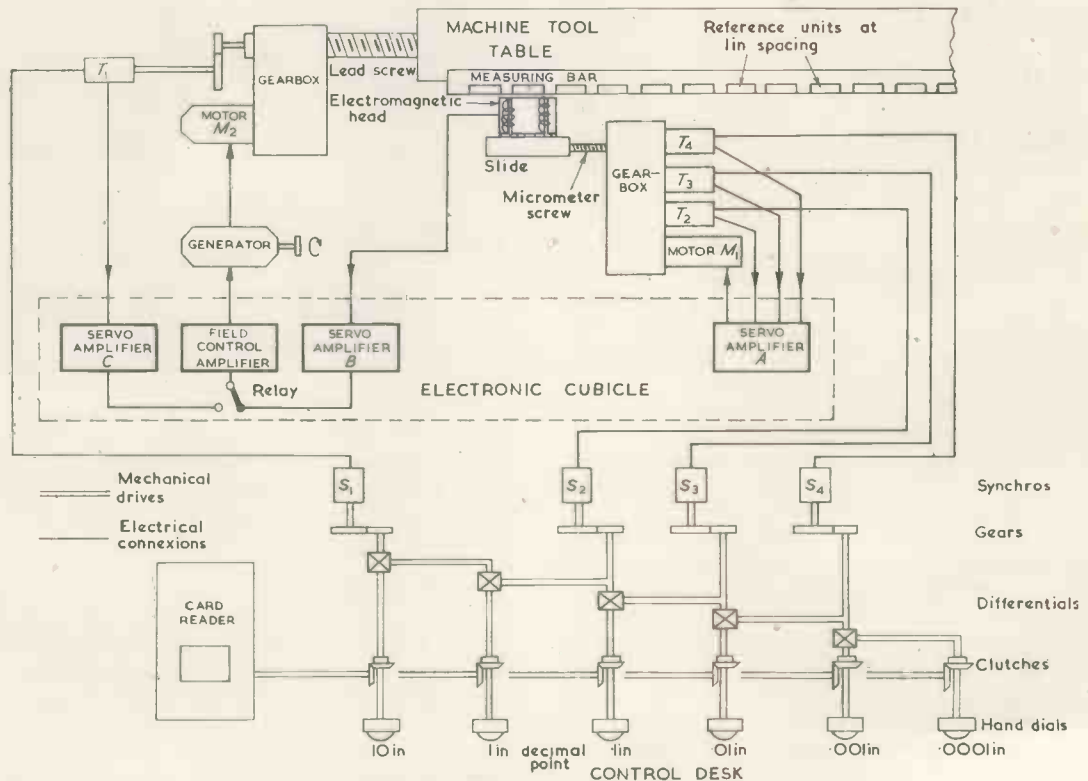


Fig. 3. General arrangement of the control equipment

described as a sequence, though in practice certain motions take place simultaneously. It will be assumed that the required co-ordinate has been set up on the six dials. Through suitable gearing the "input" synchros S_1, S_2, S_3, S_4 are rotated, and give misalignment signals in co-operation with the corresponding "output" synchros T_1, T_2, T_3, T_4 respectively.

The decimal dimension is defined by shaft rotation of S_2, S_3 and S_4 which causes the servo-amplifier A to operate motor M_1 , until $S_2-T_2, S_3-T_3, S_4-T_4$ are in alignment. High quality instrument gearing and an accurate micrometer

from the desired position, and reverses in phase for an error in the opposite direction. This permits the final approach to alignment to be made under conditions of controlled velocity and retardation of the table, so that the manner of stopping is predetermined by the electronic circuits, and not by extraneous conditions such as viscosity of lubricants, table loading, etc.

After the setting of the digit dials—by hand or card—the automatic setting of both co-ordinates on the machine tool is initiated by push-buttons, and the sequence ends by the automatic clamping of both motions.

Details of the Measuring System

The measuring bar (Fig. 4) is of heavy construction in a special steel and carries the "inch units" which are identical blocks with a $\frac{3}{16}$ in diameter hole in the face. In order to present a smooth face the holes are filled with brass inserts. The bar is set up in a temperature controlled measuring room so that the reference holes are $1.000\text{in} \pm 0.0002\text{in}$ apart. A final screwdriver adjustment is available, which through the medium of an asymmetrical steel slug in the bar allows the effective magnetic position of each hole to be shifted up to $\pm 0.0005\text{in}$. The final adjustment is preferably left until the bar is in position on the machine tool.

The electromagnetic head is essentially a differential arrangement of two transformers, the magnetic circuits of which are completed by that part of the measuring bar which faces the head.

The construction of the head is symmetrical so that it is free of changes caused by temperature, supply voltage and frequency variations, and stray magnetic fields. The gap

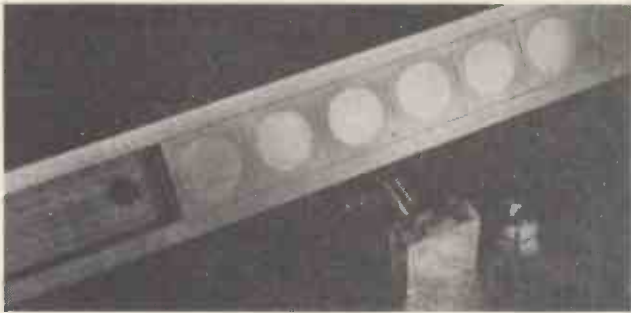


Fig. 4. The measuring bar

between the magnetic head and bar is not critical. The sensitivity of the head is such that it is capable of delivering a sufficient voltage to operate the servos with 20 micro-inches misalignment from the magnetic centre of one of the reference holes in the bar. The head carries oiled felt pad wipers which clean the face of the measuring bar.

As previously stated the sensing unit in the head is shifted by the decimal part of the co-ordinate desired, and accordingly it is carried on a short accurately made slide, parallel with the measuring bar. A high accuracy electronic servo effects the positioning through the medium of a gear box and micrometer screw. As shown in Fig. 3, coarse, fine, and very fine synchro data units are used to attain high accuracy. While reliance is placed on the accuracy of a micrometer screw to shift the electromagnetic head, the only force on the screw is that to move a mass of a few ounces in carefully made slides.

Operator's Control Desk

The control desk (Fig. 2) may be located at the most convenient position to suit the machine tool operator, since connexion to the rest of the system is by the electrical control wiring only. Appreciable space on the desk is allocated to the digit set up dials, to give clearly displayed figures and conveniently sized and disposed set up knobs. Detent action on the dial shafts gives positive location for each of the ten decimal positions of each dial.

Referring to Fig. 3, it will be seen that the synchros S_1 , S_2 , etc. are not operated directly by the dials, but through differential gears and other gearing of appropriately chosen ratios.

The differentials serve to add one-tenth of the rotation of any dial to that of the shaft behind the adjacent dial on its left-hand side. Briefly, this is necessary because of the

following considerations:

(a) In the coarse, fine and very fine data transmission between the desk and the micrometer servo, there is a fixed relationship between the rotors of T_2 , T_3 and T_4 through a normal gear train. The same apparent relationship must therefore hold between the shafts of S_2 , S_3 and S_4 in order that alignment S_2-T_2 , S_3-T_3 and S_4-T_4 may take place simultaneously and unambiguously wherever the dials are set. It would not be satisfactory to gear the dials together directly; with such an arrangement the right-hand dial would need to make a thousand revolutions for every inch change of setting. This would neither be convenient nor speedy. It is preferable that, to the operator, the dials should appear to be independent.

(b) Differential coupling is also used to the left of the decimal point. This is to ensure that no ambiguity arises if the input dials are changed from say 12.0000 to 12.9999. This would cause the electromagnetic head to be moved very nearly into alignment with the 13th unit on the measuring bar. It must not, however, be aligned with this unit, but with the 12th. Therefore, the synchro S_1 is rotated by an amount which corresponds approximately to 0.9999in and through the main servo motor M_2 brings the table nearly to the correct position as described previously.

CARD READER

This is to be seen on the left-hand side of the desk in Fig. 2. Standard size business machine cards are used, but made of a material which is impervious to oil. They can be prepared for use by means of a simple hand punch. Identification and operator's instructions are written or printed on each card, one card being used for each pair of co-ordinates.

In operation a card is taken from a stack and placed on the carriage. A "start" push button is pressed which causes the carriage with the card on it to be drawn into the reader. Simultaneously, the dials are automatically returned to their zero positions. The carriage then reverses its direction of movement and brush contacts are lowered on to the card. As the card is returned to its start position, the dials are rotated in unison. The brushes complete electric circuits through the holes in the card and when any one brush makes contact, the appropriate dial is disengaged from the driving mechanism and is left accurately positioned by means of a detent wheel and spring loaded arm.

AUXILIARY CONTROLS

In addition to automatic co-ordinate setting, milling feeds are available, and advantage is taken of the servo system in providing continuous adjustment of feeds from $\frac{1}{16}$ in to 10in per minute. Three meters are mounted on the desk, one indicating spindle horse power, and the other two indicating when coincidence has been achieved between the machine tool slide positions and the numbers set up at the desk. These are used principally for setting the datum for measurement, but may also be used as a means of checking that correct positioning has been achieved.

Performance

The accuracy required for the installation described here is $\pm 0.0005\text{in}$, but $\pm 0.0002\text{in}$ is achieved in practice. By using very accurate micrometer screws for positioning the detecting heads, and by taking advantage of the facility for fine adjustment of the 1in units on the measuring bar, the equipment is capable of $\pm 0.0001\text{in}$. The measuring bars are set at 68°F, and have the same temperature co-efficient as cast iron. Consequently, variations of shop temperature do not produce discernible errors when working on cast iron.

Electronic Switches for Television

By A. M. Spooner*, Ph.D., B.Sc., A.M.I.E.E.

A number of types of electronic changeover switches are considered, with particular reference to the cause of switching transients.

A new stable diode-type switch is described which gives a transient-free changeover lasting a fraction of a microsecond. This design of switch has been successfully used for replacing an arbitrarily-shaped area of one television picture with the corresponding area from another picture to effect scenery economy.

A WIDE variety of electronic switch circuits has been developed during the last ten years, mostly in the radar field. All these circuits are subject to certain limitations, but a particular circuit can usually be chosen to give adequate performance in a particular application.

The work described here was carried out with the object of producing an electronic switch capable of switching between two video signals without distortion. By the use of a suitable switching waveform, consisting of frame and line frequency pulses, it was required to replace a chosen area of the television picture from one camera with the corresponding area of the picture from another. This is useful for scenery economy, and the process is described by Spooner and Worswick¹.

The requirements for an electronic switch to give this result are rather severe, and no existing circuit could be found which was adequate in all respects. The switch must have a changeover taking place in a fraction of a microsecond and without introducing objectionable transients; it must have negligible attenuation from d.c. up to the highest video frequency required by the scanning standards; it must be highly stable from the point of view of relative amplitude and relative d.c. level of the two components of the switched output, and finally, there must be no "breakthrough" of one input to the output when the other input has been selected by the switch.

True double or multiple-pole electronic switches are rare, the usual method being to connect two or more on-off switches together. (An exception to this is the cathode-ray beam switching tube, which is not suitable for the purpose under consideration.) Each on-off switch consists of an arrangement of valves in which a standing current, on which the waveform to be switched is superimposed, is turned on and off by an applied pulse. In general this results in an output waveform from the on-off switch consisting of the wanted waveform superimposed on a pedestal. For the double-pole switch, the pedestal from the two on-off switches of which it is composed can be arranged to cancel out. However, practical switching pulses do not have infinitely fast time-of-rise, and if transients at the output are to be avoided the shape of the rising current waveform in one of the switches must be exactly balanced by the shape of the decaying current waveform in the other.

The formation of a pedestal can be avoided by making each on-off switch two valves in series. The signal to be switched is applied across the two valves, and the load connected between the junction point and earth. Since the same current must flow through both valves, to a first approximation it can be arranged that the potential of the junction point remains unaffected as the standing current is reduced. As the current approaches zero the impedance of the two valves increases causing the signal fed to the

load to decrease to zero. An additional complication occurs with the series switch, however, in that if the current/voltage characteristics of the two valves are not identical, during part of the switching process the two resistances will not be equal and this gives a transient disturbance on switching on and off.

For a double-pole switch, the first requirement is to obtain perfectly balanced push-pull switching pulses, and the second is to apply them to two on-off switches in such a way that a high degree of balance is preserved. In addition, the passage of the high-frequency components of the switching waveform through the valve inter-electrode capacitances must be negligible or must be balanced out. Failure to meet these requirements will result in switching transients at the output.

Generation of Push-pull Switching Pulses

Since the two on-off switches, whatever form they take, must be fed with push-pull switching pulses, it is first necessary to consider means of obtaining these pulses, balanced to the required accuracy.

Circuits involving transformers are inconvenient since the d.c. component must be preserved if the correct switching action is to be obtained, and black level clamping would have to be applied to both the switching pulses. D.C. restoration with a diode is inadmissible because the mark-to-space ratio of the pulses is variable.

The most convenient circuit was found to be the well known cathode-coupled pair, with a pentode to provide a high-value common cathode resistance. This circuit has the advantage of a very high degree of inherent low frequency balance down to zero frequency together with an easily-balanced high frequency response.

Fig. 1 shows this circuit, giving push-pull pulses from the two anodes. Two equal resistors are connected in series between the anodes to indicate the degree of balance obtained. When the signals on the two anodes are equal and opposite, there is, of course, no signal produced at the junction of the two resistors. V_1 and V_2 are normally the two halves of a double triode, the incoming pulse being connected to the control grid of V_2 and the control grid of V_1 connected to a d.c. bias. Both V_1 and V_2 are assumed to operate in class-A. The pentode V_3 , with its screen held at a suitable fixed potential and a feedback resistor in its cathode circuit, provides the high common cathode impedance which gives the desired d.c. and low-frequency balance.

The balance at the high-frequency end of the video band is affected by stray capacitances, and in particular by inter-electrode capacitances. The capacitances having the greatest effect on the balance are shown on the diagram. C_k (including the grid to cathode capacitance of V_1) slows down the cathode waveform so tending to make the output of V_1 slower than that of V_2 , whereas C_{ea} and C_{ek} have the opposite effect. The anode-to-cathode and anode-to-ground

* High-Definition Films Ltd., formerly British Broadcasting Corporation.

capacitances are balanced and do not effect the relative shape of the push-pull outputs.

In general the values of capacitance in a practical circuit will not be such that the outputs are balanced. However, by the appropriate addition of a capacitor of a few pF substantially perfect balance can be achieved. The balance can also be affected by the d.c. level of the input pulse on the grid of V_2 . This comes about with an input pulse large enough to cut off V_2 at the bottom of its swing,

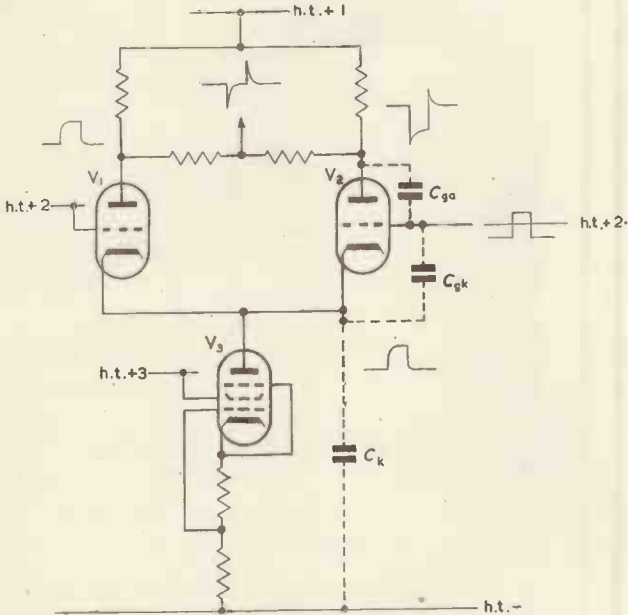


Fig. 1. Push-pull pulse circuit

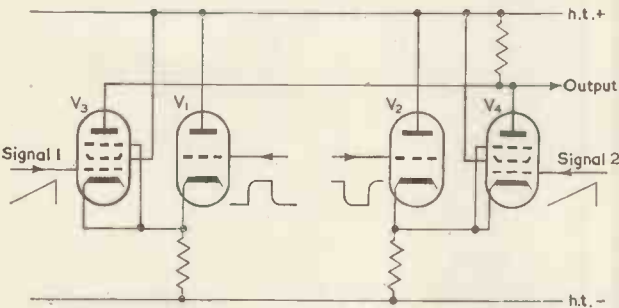


Fig. 2. Cathode-follower switch

thus removing the effect of C_k for this part of the time but having no effect on C_{ag} and C_{rk} . In practice a small variation of d.c. level of the pulse provides a useful method of setting the circuit for optimum balance.

The circuit described above was used to feed a number of double-pole switch circuits with balanced switching pulses.

Types of Switch Circuit

PARALLEL SWITCHES

Considering first the class of switches in which the two on-off elements are connected in parallel, Fig. 2 shows a circuit which gave encouraging results. V_3 and V_4 are the signal valves which feed a common anode load, and are switched in their cathodes by two switching valves V_1 , V_2 . V_1 and V_2 are fed with balanced switching pulses from a circuit such as Fig. 1. Resistance-capacitance couplings compensated down to zero frequency were used to feed V_1 and V_2 from the push-pull pulse circuit.

The circuit has several good features. It is stable, because each signal valve is either cut completely off by the pulse valve to which it is connected, or it is allowed to draw a normal cathode current through a cathode resistor large enough to minimize variation in valve parameters. It is free from "break-through", because the signal valves are pentodes and signal modulation of the control grid produces negligible anode signal when anode current is cut off by driving the cathode positive. In addition there is no difficulty in obtaining a frequency response flat from d.c. up to the highest video frequency required.

The transient conditions on switching are, however, unsatisfactory, and it is instructive to consider why this is so as the reasons have a bearing on the operation of other similar types of switch.

Switching transients are most easily visible when the areas of the television picture between which switching occurs are of the same brightness.

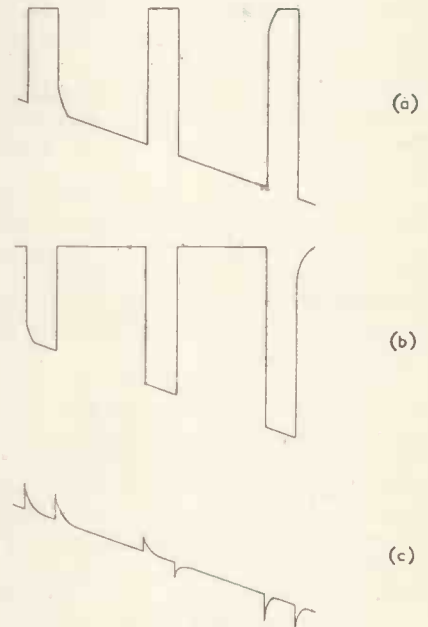


Fig. 3. Waveforms of cathode-follower switch

A sensitive test is to feed a line-frequency sawtooth into both the signal inputs and to apply a switching waveform having a number of pulses in each line. This gives a number of changeovers in each line, each changeover occurring between areas of equal brightness.

Fig. 3 shows the result of applying this test to the circuit of Fig. 2. (a) is the anode voltage waveform of V_3 with V_4 disconnected, and (b) is the waveform of the anode voltage of V_4 , with V_3 disconnected. (c) is the composite output, which exhibits transients at the changeover points.

These switching transients take the form of spikes, and vary according to the level of the video signal at the moment of switching. They are due to the fact that the input switching pulse, which must be made sufficiently large to swing the signal valve current fully whatever the level of the signal valve grid, is clipped differently according to the signal level. When the input signal is at black level, the bottom of the switching pulse is used, but when the signal reaches peak white, the top is used.

Since this difficulty cannot be avoided with this type of switch, efforts were made to speed up the edges of the push-pull pulse fed to the switch and also to decrease the effect of cathode capacitance by using a lower cathode resistance. Larger valves were used for the push-pull pulse pair feeding the switch itself, and "shunt-peaking" fre-

quency correction was applied to the anode. A considerable improvement was affected but the final ratio of maximum transient to picture was still about 15 per cent (17dB), and the outlining of the inlaid area on the picture was unacceptable.

Other types of parallel switch (i.e. two on-off switches connected in parallel) suffer from the same difficulty that clipping of the switching pulses occurs, leading to switching transients. In particular, diodes are often used, but sufficiently good cancellation of the pedestals cannot be obtained.

Following a suggestion by Mr. G. G. Gouriet of the BBC Research Department, a more elaborate version of Fig. 2 was tried, in which each switching valve operated on two signal valves, the control grid of one of the signal valves being held at a constant potential, and the video signal applied to the other. The anodes of each pair of signal valves were connected by d.c.-compensated couplings to the control grids of each of two cathode-coupled pairs, which eliminated the pulse component of each signal. The anodes of one of each of these cathode coupled pairs were connected together to provide the output. This arrangement gave a switching transient response which was almost satisfactory, but the residual transient varied with the signal modulation, and the stability was not high enough.

A popular type of parallel switch circuit is the one in which two pentodes are connected in parallel, the two video signals being fed to the control grids and push-pull switching pulses to the suppressor grids. As usually operated this circuit gives unacceptable transients on switching, but theoretically it should be possible to make the transient small.

The essential thing with this circuit is to apply switching pulses which do no more than just cut off the valves; if the suppressor grids are overdriven the pulses are clipped and switching transients appear. Underdriving the suppressor grids allows signal breakthrough. Cathode resistors must be used of large enough value to minimize the effect of variation of the valve parameters and to obtain a linear modulation characteristic.

For the above circuit to be satisfactory the push-pull switching pulses must be exactly matched, free from any amplitude drift, and held exactly to the correct d.c. level. Since there is no clipping action, any imperfections in the switching pulses appear in the signal output.

SERIES SWITCHES

Since no parallel type switch could be found that was entirely satisfactory, attention was directed to the series type. The requirement that the two circuit elements which are connected in series shall turn on and off along almost identical characteristics was tested, under d.c. conditions, for both diodes and triodes.

Two double triodes (ECC81) were connected as shown in Fig. 4. The two series switches V_1 and V_2 were connected to a common output point, and a variable voltage E_1 , obtained from a battery feeding ganged potentiometers, was used to simulate the switching pulse. The two identical batteries each providing a voltage E_2 were connected so that the "switching pulse" was fed equally to both halves of each switch.

The output potential was examined as E_1 was varied from about +20V through zero to about -20V, thus switching anode current from one valve to the other. Out of a dozen or so samples for both V_1 and V_2 , all gave an unacceptable variation of the output of one or two volts. The shape of the curve varied with the sample chosen, some curves have a maximum at the changeover point,

some a minimum, and some several maxima and minima.

Measurements on some double diodes (EB91) were sufficiently encouraging to lead to the construction of a complete changeover switch. This proved to be a satisfactory answer to the problem. Fig. 5 gives a simplified version of the circuit, from which it will be seen that each on-off switch consists of a cathode-coupled pair with a pentode for the common cathode impedance, feeding a

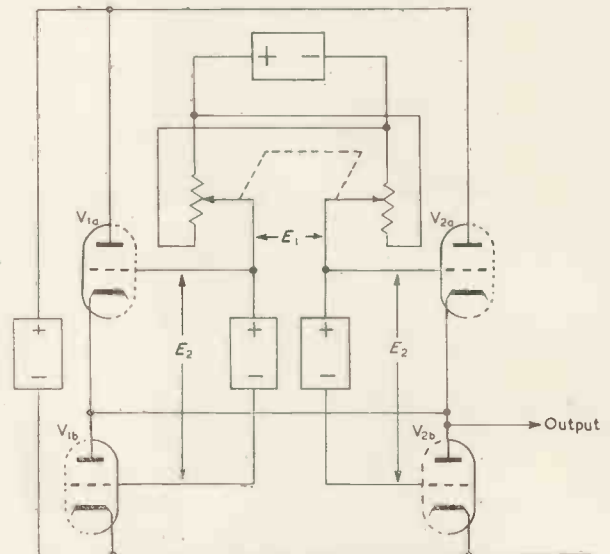


Fig. 4. Series triode switch

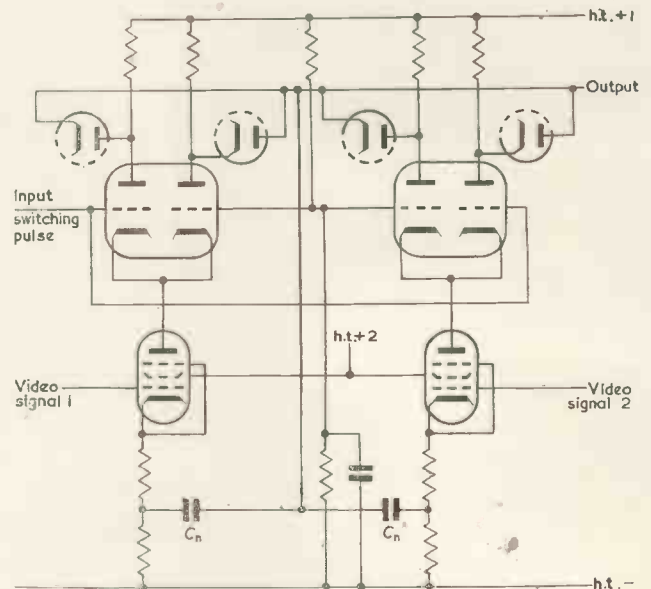


Fig. 5. Series diode switch

double diode with the diodes connected in series. The complete switch consists of two such on-off switches in parallel.

We have already seen how balanced push-pull switching pulses can be obtained from this circuit; here they are applied directly to the two diodes in series, so that the only lack of balance is in the anode voltage/anode current characteristics of the diodes. The video signals to be switched are applied to the control grids of the pentodes, so that the triodes are driven push-push by the video signal, but push-pull by the switching pulses.

The cathode feedback applied to the pentodes is suffi-

ent to ensure that the vision signals are transmitted linearly through the circuit, and to stabilize the circuit against variation in the pentode characteristics. Owing to this feedback it is possible to obtain a large ratio of signal swing to standing current in the cathodes, which again helps the stability.

Black level clamps (not shown) are applied to the control grids of the pentodes and can be set so that in the composite output of the circuit the black levels match. The relative amplitudes of the two applied vision signals can then be adjusted so that a match is also obtained at peak white. The circuit is then correctly set up and will not need further adjustments until ageing of the components produces a slight lack of balance.

If it were not compensated for, "break-through" of the switched-off video signal to the output would occur, since the switched-off diode still has a push-pull video signal applied to it, and its inter-electrode capacitance would pass the high frequency components to the output. Break-through is completely eliminated (better than 56dB down) by feeding an antiphase signal from the cathode circuit of each pentode through a neutralizing capacitor C_n to the output point. Without compensation, the break-through is about 44dB down and is unacceptable.

As mentioned previously, the provision of accurately balanced push-pull switching pulses depends on the capacitances involved in the pentode-triode circuit. With the valves used (EF91, ECC81) the balance was almost correct without the addition of trimming capacitors. A slight adjustment of the d.c. level of the incoming switching pulse provided a convenient means of setting the residual switching transients to a minimum.

The residual transients were not greater than 2 per cent of the picture amplitude (34dB down) and did not vary with the picture information. The visibility of the change-over on a composite 405 line picture on a grey area was

about equal to the visibility of the scanning lines. For changeovers between areas of different brightness the changeovers were invisible.

Heater voltage changes of ± 5 per cent and h.t. voltage changes of $\pm 25V$ produced no change in the match between the two components of the output picture. Different triode and pentode samples of the same valve types gave small changes in balance which could be taken up with the video black level clamp controls.

Of a large number of double diode (EB91) samples, some 20 per cent gave switching transients which were outside the limits stated. These samples had current/voltage characteristics which were insufficiently balanced for the rather exacting requirements. Since the remaining 80 per cent were satisfactory, however, the necessity for selecting the diodes was not considered serious.

Conclusions

The circuit finally developed is very satisfactory for the purpose for which it is required. The investigation which led to it throws some light on the causes of switching transients in other types of electronic switch circuit.

The new circuit may prove useful for other purposes than the main one; for example as a single on/off switch feeding a load it becomes a very stable suppression mixer, and as a triple on/off switch it may have applications in colour television.

Acknowledgments

The author wishes to thank Mr. F. W. Nicholls of the BBC Designs Department, who was responsible for carrying out the experimental work and for making contributions to the design of the different circuits.

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1. SPOONER, A. M., WORSICK, T. Special Effects for Television Studio Productions. *Proc. Instn. Elect. Engrs.* 100, Pt. 1, 288 (1953).
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New Computing Service in London

The English Electric Company has extended its computing service by starting a new centre in its London Office, Marconi House, Strand, W.C.2.

This centre is part of the Nelson Research Laboratories and operates in close collaboration with the organization at Stafford. This service which is available to organizations outside the English Electric Group is provided by the DEUCE* (digital electronic universal calculating engine). The machine is manned by a team of mathematicians specializing in the application of high speed digital computing to problems in all branches of mechanical and electrical engineering and communications, aircraft, civil engineering and commerce.

The computing service has behind it an extensive library of programmes and sub-routines which have previously been prepared for the solution of many and varied problems. This library is compiled from all establishments who are using the DEUCE extensively and will be available to those using this new computing service in London.

In the centre foreground of the illustration an operator at the control desk is preparing the punched cards which give the machine its instructions and data for working out a particular problem.

On the right another operator is removing the cards giving the solution of a problem from the output machine. The

input machine for feeding in the instruction cards is on the left. Behind are the cubicles containing the main electronic units and the magnetic recording drum. On the right at the rear of the picture is the mushroom shaped thermostatic container which holds the machine's high speed memory. The cubicles and control desk occupy a total floor space of 14ft by 4½ft.

A general view of the English Electric computing centre



* *Electronic Engng.* 27, 179 (1955).

A Wide-Range RC Phase-Shift Oscillator

W. Fraser*, B.Sc. (Eng.), A.M.I.E.E.

A simple form of RC oscillator, which employs valve phase-shift circuits, is described. Whereas previous arrangements have used a.c. coupling, it is shown that d.c. coupling may be used with advantage, and the low frequency range of the oscillator extended. Two oscillator circuits and a suitable output stage are given. The application to polyphase oscillators is also discussed.

THE phase shifting circuit of Fig. 1(a) is well known^{1,2} and has the merit that it can be used to produce phase-shifts over a wide range of frequencies without change in amplitude of the output voltage. This condition is achieved if the impedance of the branch containing the variable element is large compared with the resistive branch, and if the impedance of the load connected to the output terminals is very high; the current drawn from the source is then constant in magnitude, and an output of half the applied voltage is obtained.

If the resistors R_0 form the anode and cathode loads of a valve, the familiar valve phase-shift circuit³ is obtained. In this case, the points marked B and C in Fig. 1(a) are connected to the anode and cathode respectively, while the mid-point A is conveniently at earth potential. The overall stage gain is less than unity and usually lies between 0.4 and 0.5. One or more stages of phase-shift combined with an appropriate maintaining amplifier enables a simple form of oscillator to be produced^{4,5}. Such oscillators have employed conventional a.c. coupling. It has been found that "direct" coupling of the stages, and elimination of decoupling capacitors, enables the circuit to be simplified and the frequency range of the oscillator to be extended. An oscillator of this form may be arranged to operate from less than 1c/s to well over 100kc/s.

Basic Circuit

The basic circuit is shown in Fig. 2, from which it will be seen that V_1 and V_2 are phase-shift stages and V_3 is a maintaining amplifier.

Inspection of the vector diagram of Fig. 1(b) indicates that a phase-shift of 90° is produced when the reactance of C is equal to the value of the resistance R . Each of the phase-shifting stages shown above is required to give this phase-shift to make the circuit oscillatory, and so the frequency of oscillation is given by

$$\frac{1}{\omega C} = R + R'$$

$$\text{and so } f = \frac{1}{2\pi C(R + R')} \text{ c/s} \dots \dots \dots (1)$$

when the resistance is measured in ohms and C in farads. The two variable resistors are ganged and form the tuning element, together with the resistors R' , which are inserted to provide a limiting minimum value of resistance. The capacitors are switched according to the frequency range desired.

The values of the components used are not at all critical, except that the pair of resistors R_0 in each phase-shift stage should preferably be matched to about 1 per cent. The values of R_0 in the second stage need not be identical with those of the first stage. Other types of valve may be used and the valves V_1 and V_2 may be halves of a double triode. The performance of the circuit, and the purity of the waveform produced does however depend on the provision of adequate negative bias for all

the valves. This should be about one volt or more and should be checked for any other type of valve. The maintaining amplifier is required to compensate for the loss in the first two stages, and incorporates a thermistor to maintain a constant output. The value of the resistor connected

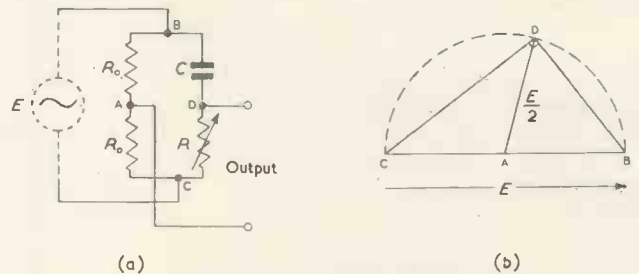


Fig. 1. Phase shifting circuit

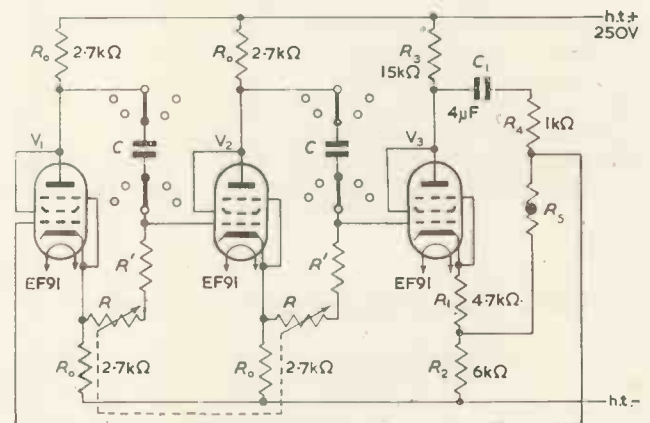


Fig. 2. The basic circuit

$R_5 =$ S.T.C. type A1522/100 Thermistor

in series may have to be changed if a different type of thermistor is used.

Frequency Range

For any given value of the capacitors C in the phase-shift stages, the frequency range is determined by the ratio of the maximum to minimum value of resistance in the variable arm. In terms of the components in Fig. 2 the

$$\text{frequency ratio} = \frac{(R_{\max} + R')}{R'}$$

where R_{\max} is the maximum value of a section of the potentiometer R . Now equation (1) indicates that the frequency of oscillation is inversely proportional to the resistance in the variable arm. If the sections of the ganged potentiometer are linear, then a non-linear, or non-uniform, scale calibration is obtained. As it is preferable to have a fairly "open" scale it is convenient to limit the maximum/minimum frequency ratio to something less than 4:1, and extend the range by switching different values of C . A value of $22k\Omega$ for each of the resistors R' has been

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chosen, to give a frequency ratio of 3:3:1 with 50k Ω potentiometers. This arrangement has been used with ten values for the capacitors C to produce an overall frequency range of 1c/s to 100kc/s.

The first remarkable feature of the circuit is its ability to oscillate quite readily and stably over an extraordinary frequency range with complete freedom from any "parasitic" or other undesired mode of oscillation. It has been found that with larger values of variable resistance ($R=1M\Omega$), the circuit is capable of oscillation at frequencies lower than 0.1c/s. It seems likely that if the apparent value of capacitance was artificially increased by circuit modification⁶ to make use of "Miller" effect, the actual size of capacitor required would be decreased, or alternatively, the lower frequency limit could be extended. At the high-frequency end of the range, frequencies as high as 1Mc/s have been produced.

Another striking feature of the oscillator is the constancy of the output voltage produced by it. With correct adjustment it is possible to achieve an output which is level from 20c/s to 100kc/s within ± 0.2 dB. Below 20c/s the output tends to increase slightly with decreasing frequency.

Waveform

As far as the output waveform is concerned the distortion is small, and harmonic measurements on the sine wave output of the oscillator over the range from 20c/s to 20kc/s show that the total harmonic content is less than 0.5 per cent. Beyond these limits there is no visible deterioration in the waveshape.

While no precise measurements of frequency drift have been made, the laboratory use of this form of oscillator has shown that the frequency stability is good, and certainly very much better than that of the conventional form of beat-frequency oscillator.

Alternative Circuit

The arrangement shown in Fig. 2 has two disadvantages. First, the presence of the capacitor C_1 produces a significant phase shift at the lower frequencies, and so in a multi-range version of the oscillator the frequency ranges below 100c/s require individual calibration. Secondly, the temperature sensitive thermistor causes a fall in the output voltage after the oscillator has been running for some time. Adequate ventilation of the oscillator case will minimize this effect. Most of the drop in output level, about 5 per cent, occurs in the period of 30 minutes after switching on. These disadvantages may be overcome if the circuit of the maintaining amplifier is arranged as shown in Fig. 3. This involves a negative supply of 200V. Neither this nor the high-tension supply need however be stabilized. This is also true for the circuit of Fig. 2.

With the circuit of Fig. 3, and say, a ratio of 3:3:1 in the value of the tuning resistance only two scale calibrations are necessary for the complete range of frequency. Thus the calibration can extend from 0.95 to 3.13c/s in the first range, then 3.03 to 10c/s in the second range, 9.5 to 31.3c/s in the third, and so on. With this circuit there is a slight change of output level (about 5 per cent) from one end of one frequency range to the other; this arises from a small change in amplitude with phase shift in the phase-shifting stages. It may be minimized by using lower values for the resistors R_0 , or higher values for the tuning resistors.

Output Stage

Because of the wide frequency range covered by the oscillator it is not convenient to use a transformer in any output stage connected to it; a low-impedance output may

be obtained by the connexion of a cathode-follower. The circuit is admirably suited to a push-pull output stage however, and the arrangement that has been adopted is shown in Fig. 4. It will be seen that this consists of two valves arranged as cathode-followers; one is fed from the anode and the other from the cathode of the first phase-shift stage. This arrangement enables a balanced output to be obtained; alternatively an unbalanced output may be obtained from one terminal and the centre tap.

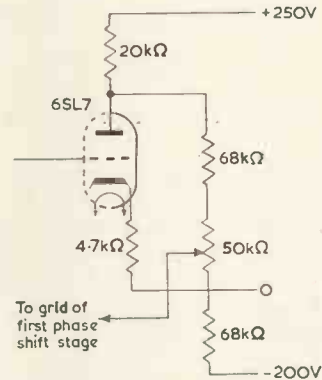


Fig. 3. Alternative circuit

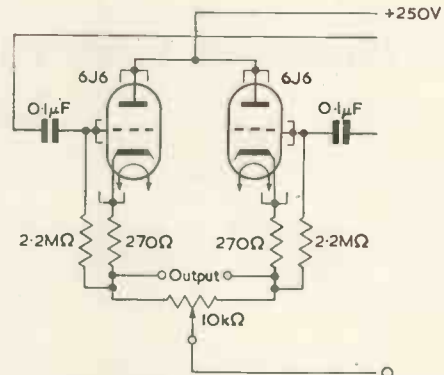


Fig. 4. Push-pull output stage

circuit has the useful feature that d.c. may be eliminated from the output connexion.

The open-circuit output voltage with the values shown is 6V r.m.s. With an external load of 2k Ω an output of 5V is obtained.

Polyphase Operation

Any closed loop circuit which has a total phase-shift round the loop of $0, 2\pi, 4\pi \dots$ radians, will be oscillatory if the loop gain is at least equal to unity. If such a system is to be used as a variable frequency polyphase generator it is essential for simplicity of operation that the phase-shifting elements should have an attenuation which is independent of frequency. The circuit of Fig. 1(a) meets this requirement to a high degree of approximation, and so a valve phase-shift stage followed by an amplifying stage with a gain of approximately two can be adjusted to give a circuit of unity gain and variable phase. If n such circuits are connected in cascade to form a closed ring the whole system then functions as a very simple n -phase generator.

A three-phase oscillator has been constructed on these lines and found to be very satisfactory. One phase is shown

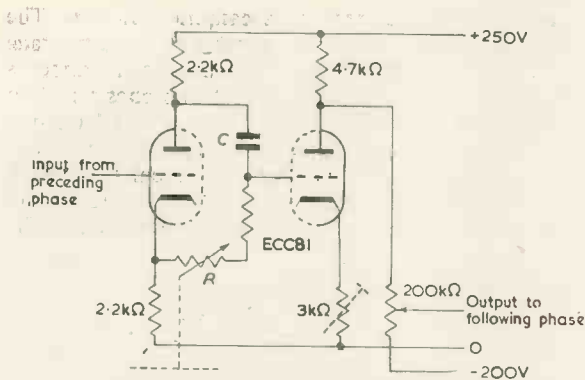


Fig. 5. One phase of polyphase oscillator

in Fig. 5. The other phases are identical, and tuning is affected by a three-gang potentiometer with a section as the variable resistor *R* in each of the three phases; the three capacitors *C* are then switched according to the range required. The circuit shown in Fig. 5 indicates the use of a third type of valve; there is no restriction to this type and other valves may be used.

With a three-phase system the phase-shift required in each of the phases is 120°, and it is a simple matter to show from the vector diagram of Fig.1(b) that the condi-

tion required is

$$\frac{1}{\omega CR} = \tan 60^\circ$$

and so the frequency of oscillation in this case is given by

$$f = \frac{1}{2\pi CR\sqrt{3}} \dots \dots \dots (2)$$

If a pair of cathode-followers are connected to the anode and cathode of each of the three phase-shift stages the system can give a six-phase output, should this be desired. For three-phase operation three cathode-followers have been used, one connected to each of the junctions between the phases of the system.

It has been found necessary to keep the corresponding components in the three phase-shift networks matched to about 1 per cent. With this proviso, the performance of the polyphase oscillator will be found to be similar to the single-phase oscillator.

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A Grounded Grid Valve System with High Stability Characteristics

By F. Exley*, B.Sc., Grad.I.E.E., and R. E. Young*, B.Sc., A.M.I.E.E.

High stability with grounded grid valves in coaxial line cavities is obtained by converting "lighthouse" valves into double ended ones; i.e. a physical arrangement is produced in which the anode and grid cavities are disposed on opposite sides of the common grid plane. An oscillator is considered in detail as it is felt that the problems associated with it are greater than with the corresponding r.f. amplifier.

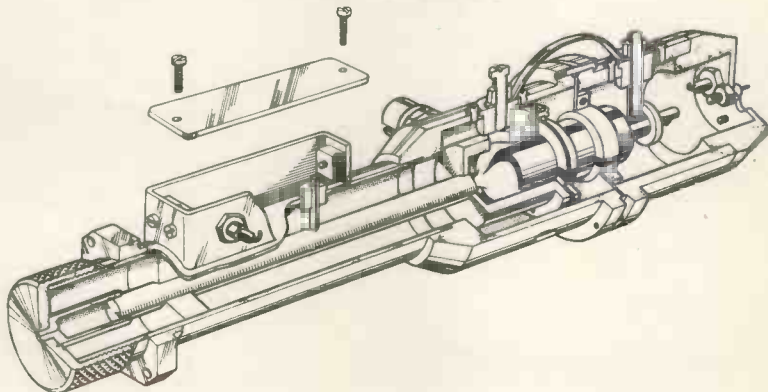
THE original form of grounded grid valve as developed in this country was used, in general, with coaxial line cavities which extended on either side of the common grid plane. The final stage of this valve development was probably reached with the CV88 which was designed basically for use in r.f. amplifiers¹.

Later grounded grid valves of the "lighthouse" type of construction were associated with a mechanical arrangement in which the anode-grid and cathode-grid cavities extended in the same direction. This mechanical form is considered to have disadvantages which are largely overcome in the system to be described.

In this system the "lighthouse" valves are converted into "double-ended" ones, the anode and cathode coaxial cavities being disposed in opposite sides of the common grid plane. Other mechanical artifices including the use of metals such as invar with its low thermal expansion properties have been utilized to produce oscillators and r.f. amplifiers of high frequency stability. In the description of the system, a typical oscillator is taken, as it is felt that in many ways the problems associated with it are greater

than those in the corresponding amplifier. Development of the basic design has been carried out for use both as a local oscillator for use in u.h.f. receivers, and as an oscillator for use as a small transmitter. This work was undertaken as part of a private venture programme which culminated in the demonstration of a specialized form of air to ground television by Sir W. G. Armstrong Whitworth Aircraft Ltd. and described in the June, 1955 edition of Hawker-Siddeley Review.

Fig. 1. Sectional view of u.h.f. oscillator



* Sir W. G. Armstrong Whitworth Aircraft Ltd.

U.H.F. Oscillator

From the sectional view (Fig. 1) and the photograph (Fig. 2), it will be seen that an adaptor is used to extend the anode cavity away from a corresponding grid plane adaptor. In this particular application the valve cathode is isolated by an r.f. choke rather than by using a $\lambda/4$ line. In the conventional arrangement, the cathode line may be made as much as $7\lambda/4$ in length in order that a suitable feed point may be obtained². The present form of construction thus gives a much more compact piece of equipment in comparison with the former type.

It will be seen that the anode line is supported by a p.t.f.e. disk insulator, the h.t. supply being fed through decoupling components in the rectangular screened box to a low impedance point on the line. The plane extension of the grid adaptor is clamped between the anode and cathodeouters thus grounding the grid directly. If a connexion is required to be made to the grid for the purpose of grid modulation, mica insulators can be introduced in either side of the adaptor, the capacitance so formed serving to ground the grid to r.f. A tab washer is then also included in the adaptor to bring out the grid connexion. The heater supply is fed in through decoupling components housed inside the cathode outer. The r.f. output is taken through a single coaxial connector from a capacitance adjacent to the anode adaptor.

Feedback between the anode and cathode necessary to produce oscillation is introduced and controlled by an adjustable probe in the anode cavity, this being linked directly to the cathode. It is possible to adjust this probe so that oscillation is maintained without further adjustment over the wide frequency band which can be covered by this type of oscillator. This useful property is often not realized in other designs where readjustment of feedback is necessary even with a relatively small change in frequency. An associated minor advantage which springs from the new form of construction is the ease with which the feedback can be set as a mechanical operation.

Originally the tuning capacitance was in the form of a parallel plate capacitor employing two disks, one situated in the knurled tuning cap and the other at the end of the inner conductor of the anode cavity. This type of tuning however is prone to a relatively large capacitance change as the line expands due to heating by the valve. This results in a frequency drift as the oscillator warms up. Consequently, this type of tuning was replaced by a concentric sleeve which moves over the centre conductor, this resulting in a much smaller change in capacitance due to the line expansion.

Fig. 2. The u.h.f. oscillator

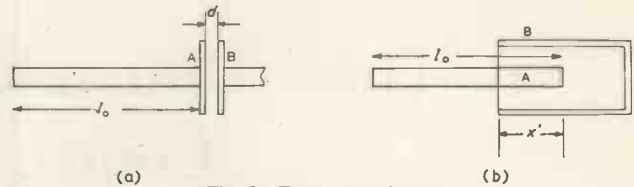


Fig. 3. Tuning capacitance
(a) Parallel plate (b) Concentric sleeve

The following compares the two methods;—

(a) PARALLEL PLATE (Fig. 3(a))

Initial capacitance between A and B, $C_0 \propto (1/d)$ and if the line expands by an amount δl , final capacitance between

$$A \text{ and } B, C_t \propto \frac{1}{d - \delta l}$$

Also $C_t = C_0 + \delta C_p$, where δC_p is the corresponding change in capacitance.

$$\therefore \text{Percentage change in capacitance} = \frac{\delta C_p}{C_0} \times 100 = \frac{\delta l}{(d - \delta l)} \times 100$$

(b) CONCENTRIC SLEEVE (Fig. 3(b))

Initial capacitance between A and B, $C_0 \propto x'$ and if the line expands by an amount δl , final capacitance between A and B, $C_t \propto (x' + \delta l)$

Also $C_t = C_0 + \delta C_s$, where δC_s is the corresponding change in capacitance.

$$\therefore \text{Percentage change in capacitance} = \frac{\delta C_s}{C_0} \times 100 = \frac{(\delta l/x')}{x'} \times 100$$

Hence:

$$\frac{\text{Percentage change in capacitance using parallel plates}}{\text{Percentage change in capacitance using a concentric sleeve}} = \frac{x'}{(d - \delta l)} = (P/S)$$

With the particular oscillator on which measurements were taken, the ratio P/S was found by experiment and by calculation, and close agreement obtained to a value of 2.4. Mention should be made here that these tests were made at the low frequency end of the band where expansion effects are, of course, more pronounced by virtue of the close proximity of the plates in the parallel plate case.

Early models of the oscillator employed silver plated and rhodium flashed brass anode inner lines and a further reduction in the frequency drift was obtained by using similarly treated mild steel lines (α brass = $19 \times 10^{-6}/^\circ\text{C}$, α steel = $11.4 \times 10^{-6}/^\circ\text{C}$, mild steel). In the final version, mild steel was replaced by invar steel ($\alpha = 1.0 \times 10^{-6}/^\circ\text{C}$) with still better results.

In this final form a 6-hour test with the oscillator set at 460Mc/s showed negligible change in frequency after allowing a two minute warm-up period.

Cooling is achieved by virtue of the mass of steel forming the anode line adaptor which is in and around this adaptor. A high power oscillator of similar design is at present under construction and it is expected that in this case it may be necessary to provide further cooling by circulating air through the centre of the anode inner conductor which will then be in tube form rather than rod.

It is considered that the form of construction has been arranged successfully to give good cooling and good frequency stability, the latter being better than 1 part in 10^4 .

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A Three-Dimensional Machine Tool Control System

A new electronic control system for a vertical milling machine has recently been demonstrated by Ferranti Ltd, of Edinburgh.

The essential elements of the system are:

- (1) An optical diffraction grating system associated with each plane of the machine tool with an inherent accuracy better than that of the machine tool itself.
- (2) A high performance servomechanism.
- (3) A digital computer which can provide the requisite service to a large number of machine tools.
- (4) A control unit associated with the machine tool and its servomotor.

The Optical Measuring System

The essential element of the measuring system is a length of optical diffraction grating carrying a line structure with a precisely known number of lines to the inch¹. The direction of the lines is at right-angles to the length of the grating.

When two sections of such a grating are superimposed so that one is tilted slightly with respect to the other, a Moire fringe pattern with an approximately sinusoidal distribution of intensity is produced as a result of the integrated interference effects caused by the angular intersection of the individual lines on each grating. When one grating is moved with respect to the other in a direction at right-angles to its line structure, the fringe pattern travels at right-angles to the direction of movement, the sense of this pattern movement depending upon the direction of relative travel of the two gratings. A relative travel of one line width on the gratings will cause a complete cycle of light and darkness on the interference pattern to pass the point examined. The width of the dark and light bands can be made sufficiently great to enable detection of individual bands to be readily achieved by the use of a photo-sensitive element. It will be seen, therefore, that if the number of dark and light bands passing a particular point, which can be defined by the position of the photo-sensitive element, are counted, a precise measure of the amount of displacement of one grating with respect to the other is obtained providing the number of lines to the inch on a given piece of grating is known.

The photo-sensitive elements convert the light intensities into electrical signals of equivalent intensity. These waveforms are used to form a digital measuring system of two pulses per grating line.

In order to discriminate direction, two points on the pattern are inspected. These are separated by an odd

number of quarter wavelengths of the pattern and their outputs form a two-phase electrical system from which directional information is readily obtainable.

This measuring system is entirely free from friction or wear and can be installed in close proximity to the part being machined. Moreover, since information is being obtained from a relatively large area of grating, the interference pattern being an integration of a large number of intersections, lengths of grating can be placed end to end with small gaps if necessary. The absence of a few lines merely lowers the contrast of the pattern by a corresponding amount. By the same token, dust and scratches have little effect.

In practice a measuring system is installed for each

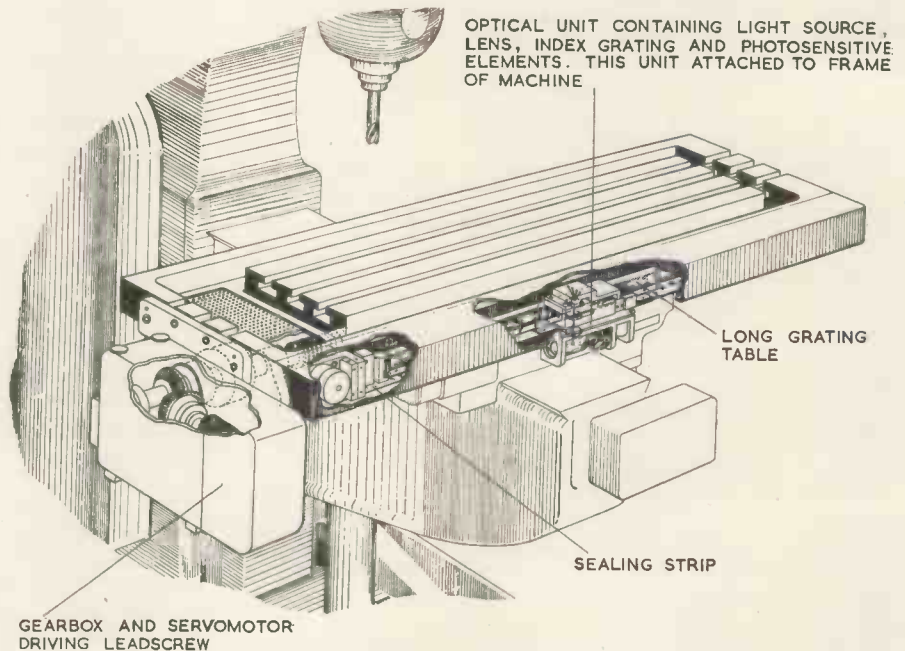


Fig. 1. Installation of servomotor drive and measuring system fitted to the table of the vertical milling machine

direction of movement which it is desired to control. On a milling machine required to do three-dimensional contouring work, three grating systems are required.

Servomotors and Milling Machine

The servomotors operating the lead screws of the milling machine are three-phase 400c/s induction motors delivering 0.5 b.h.p. at 10 000 rev/min and fed by high-performance magnetic amplifiers. These motors are fitted with a magnetic drum brake to lock the slides when the motor is de-energized; this brake also operates as an emergency stop if the machining tolerances are exceeded or when the limits of travel of the slides are reached. The motor drives through a backlash-loaded gearbox.

The reduction ratio of the standard gearbox gives an output shaft speed of 120 rev/min at peak motor power. The output shaft is arranged to drive in three planes to allow for variation of machine geometry, and a self-aligning

torque-limiting coupling is fitted to safeguard the gearbox from overload. This couples on to the leadscrew, and backlash loading is employed on the machine feeds using recirculating ball leadscrews, in order to keep the transmission efficiency high under conditions of preload.

The layout of the gearbox and measuring system on one slide of a vertical milling machine is shown in Fig. 1.

Programming

The part to be machined is designed and drawn in the conventional manner, but in place of dimensions being specified as lengths between specific points, or radii, all significant points are specified as positions relative to a system of axes. The system of axes is quite arbitrary, the only requirement being that the origin shall not be within the workpiece so that negative values are avoided. The units of measurement of the system are decimal fractions of an inch.

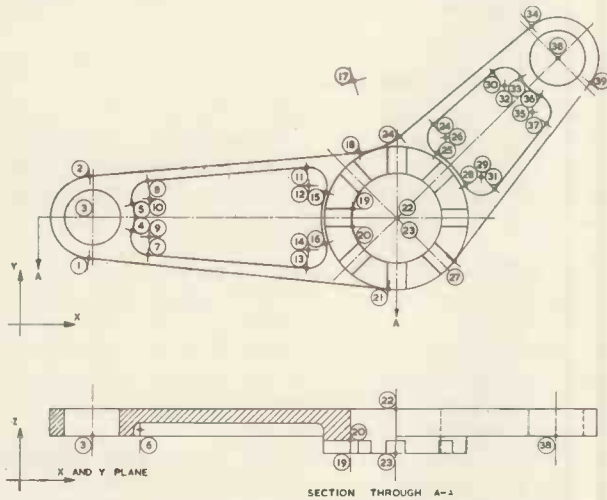


Fig. 2. A control line requiring machining in three dimensions. The co-ordinates of the change positions are shown in Table 1.

The points to be specified are the points of change from one curve to the next, or the change from a straight line to the arc of a circle and so on. Where a curve other than a straight line is required it is, of course, necessary to specify further information.

Fig. 2 shows a simple lever which is to be machined from the solid, and after supplying the basic machining information such as cutter diameter and rate of feed, the next step is the transfer of the dimensional data.

The first operation will be to machine the profile from point 1, through 21, 27, 39, 34, 24, 18, 2 and back to 1, that is in a counter clockwise direction for external surfaces.

For the machining of internal surfaces the direction of travel of the cutter is in the reverse direction. The first cut will be a straight line from the point 1 to 21, while from point 21 to point 27 the cut will be in an arc of a circle and so on back to point 1.

A planning sheet is prepared containing the co-ordinates of the various points with the direction of travel of the cutter from point to point.

The planning operations proceed in this way until every movement necessary to produce the part has been specified.

For most purposes the direction of motion will be a straight line, circle, ellipse, parabola or hyperbola, but sometimes shapes which cannot be specified in this way are required. Normally these curves can be expressed in terms

TABLE

Co-ordinates of Change Positions referred to in Fig. 2

CHANGE POINTS	X CO-ORD	Y CO-ORD	Z CO-ORD
1	0.942	0.941	1.000
2	0.955	2.061	1.000
3	1.000	1.500	0.625
4	1.534	1.323	0.625
5	1.538	1.665	0.625
6	1.656	1.500	0.719
7	1.749	0.995	0.625
8	1.760	1.988	0.625
9	1.771	1.244	0.813
10	1.777	1.739	0.813
11	3.979	2.134	0.625
12	3.995	1.884	0.813
13	3.997	0.795	0.625
14	4.019	1.044	0.813
15	4.234	1.811	0.625
16	4.254	1.131	0.625
17	4.485	3.348	—
18	4.565	2.351	1.000
19	4.638	1.625	0.563
20	4.638	1.375	0.563
21	5.147	0.505	1.000
22	5.250	1.500	1.000
23	5.250	1.500	0.375
24	5.107	2.565	0.625
25	5.760	2.432	0.625
26	5.880	2.652	0.813
27	6.048	0.897	1.000
28	6.202	1.971	0.625
29	6.426	2.082	0.813
30	6.612	3.583	0.625
31	6.623	1.928	0.625
32	6.771	3.390	0.813
33	6.996	3.501	0.625
34	7.150	4.190	1.000
35	7.159	3.013	0.813
36	7.264	3.239	0.625
37	7.355	2.858	0.625
38	7.500	3.750	0.625
39	7.949	3.411	1.000



Fig. 3. The digital computer with its teleprinter and tape reading unit

of ordinates, and if they are inserted in the planning sheet with a suitable instruction the computer will produce a smooth curve through the ordinates.

When the planning is complete, the next stage is the encoding of this information in a form suitable for use as the input to the computer.

The encoding consists essentially of the preparation of punched tape by a teleprinter which simultaneously types the information for checking purposes.

The Digital Computer (Fig. 3)

It is the function of the computer to provide continuous instructions to the machine tool as to the paths it has to follow in order to produce the part, taking into account the cutter diameter and the cutting speed specified. It performs the necessary calculations to describe the path of the centre of the cutting tool as movements in each axis in terms of the measuring systems fitted to these axes.

The paper tape, bearing all the information on the planning sheet, is the input to the computer. This information is read group by group by the computer which is equipped with circuits which recognize the instructions and dimensions as they appear.

The measuring system operates in terms of electrical impulses, each one of which corresponds to a definite and very small displacement. If a movement is in one direction and parallel to one axis, then there will be an output from one measuring system only, but any other movement will be made up of a combination of movements in at least two directions, and while it is taking place electrical impulses will appear from a corresponding number of slides. An oblique straight line in the XY plane will be made up of movement along the x as well as the y axes, the relative number of impulses appearing from each measuring system being a measure of the angle which the line makes with each axis. In the case of a curve the relative rates of appearance of impulses changes continually. The output of the computer is in terms of these impulses, a separate channel being provided for each axis of movement. The output of the computer is recorded on magnetic tape,

parallel channels on the same tape being used for each dimension, and also for providing checking information and switching instructions to the machine tool. This indirect link between the computer and the tool allows advantage to be taken of the extremely high speed at which the computer operates, and enables a single computer to provide control tapes to a number of machines. The recording speed is eight times the playback speed, and thus if each tool is required to make only one of any type of part, the ratio of machines per computer is 8:1. Normally the duplication rate will be higher than this, and it is anticipated that on average one computer will be able to provide service to 50 machine tools.

In order to allow concerns which only have a requirement for a small number of machine tools to take advantage of the system, a computer service is available whereby users can purchase the time on a computer without requiring to possess one. They will despatch either planning sheets or paper tapes to the computer centre and receive in exchange reels of magnetic tape carrying the instructions for their tools.

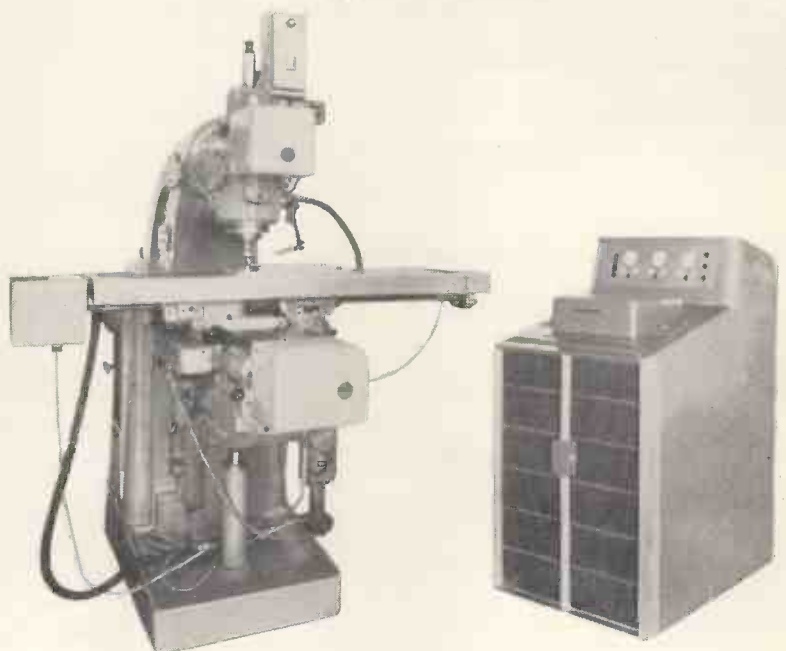
Machine Tool Control Unit

Associated with each machine tool is a control console, Fig. 4, containing equipment for reading the multi-channel tape and converting its instructions into controlled power for the servomotors whose operation is accurately monitored by the measuring attachments on the slides of the machine.

The prepared magnetic tape, which is contained in a cassette for protection and ease of handling is loaded into the tape reader. Before commencing machining the tool must be located at the datum position of the machine which will normally be used as the origin of the system of axes in planning. This positioning is automatic, but it is, of course, necessary to ensure that the workpiece is suitably located. This initial positioning having been done, the machine can proceed under the control of the magnetic tape, and no human intervention is necessary thereafter. Actions such as tool changing, coolant feed and changes

Fig. 4. The vertical milling machine (left) and the control unit with the magnetic tape deck

The three large and six small cathode-ray tubes on the control unit are for checking and monitoring purposes.



in spindle speed can, if required, be performed automatically by control signals on the magnetic tape which have been specified at the planning stage.

The action of the servo-mechanism is to lock the pulse train coming from the diffraction-grating measuring system to the command pulse train from the tape within an accuracy of one pulse. The position of the slide thus does not deviate from its true position by more than one unit. Under conditions of machine vibration, which vary greatly from machine to machine and with the cutting process, a ripple may be superimposed, but this does not affect the mean position of the table, and control is maintained.

Checking Procedures and Reliability

In both computer and control console, circuits have been standardized as far as possible, and except in the case of power packs and magnetic amplifiers, are in the form of small cards (see Fig. 4) which are inserted in removable

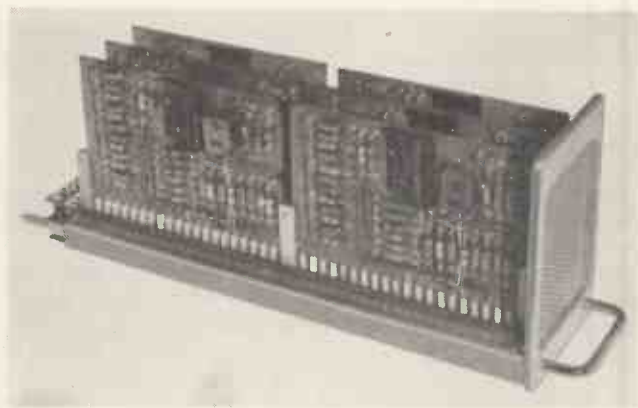


Fig. 5. Removable tray with its associated card circuits

These card circuits contain the required components which are dip-soldered. The wiring is printed.

trays to facilitate rapid maintenance and checking. The circuits have been designed so that all components, including valves, can change their characteristics by a minimum of 30 per cent simultaneously in the worst direction before there is an adverse effect on the operation of the equipment. Provision has been made for fault location by monitor cathode-ray tubes, and the tolerancing of individual circuits is such that normally no adjustments have to be made on replacement of units.

Provision is made for a number of checks throughout the various stages in the operation, including automatic continuous monitoring of the performance of the control unit and the machine tool. The extent to which the checking procedure during the early stages is to be used will depend upon individual experience and the reliability of the operators.

Since the use of teleprinters is widespread, standard equipment is available for carrying out routine checks upon the performance of the operator. The standard approach to checking is to arrange that the planning sheet is typed by two different operators, and a comparison made of the resulting tapes. As it is unlikely that two operators will make an identical error, individual mistakes will thus be detected.

The computer and the machine tool control units are equipped with means for reducing the supply voltage to each tray during the reading of a special tape. This marginal test will bring to light any potentially defective units which can be replaced before a service failure occurs.

Precautions can be taken in programming a large scale machining operation by arranging that the tool movements complete a number of closed loops. On the completion of each loop summation of pulses in each axis will be zero if no errors have occurred.

In spite of inherent reliability, the occasion will arise when, due to supply failure, component failure or other cause, some section of the equipment ceases to function correctly. It is important in such cases that the machine should be shut down before any damage is caused to the work. In order to do this, a checking system has been devised, which protects against the failure of any part of the equipment from, and including, the tape to the measuring system. The action of this is as follows: assuming that there are three control channels x , y and z , a fourth channel is included for checking purposes. When the tape is being recorded by the computer, a pulse train is recorded on this fourth channel, the number of pulses on which is

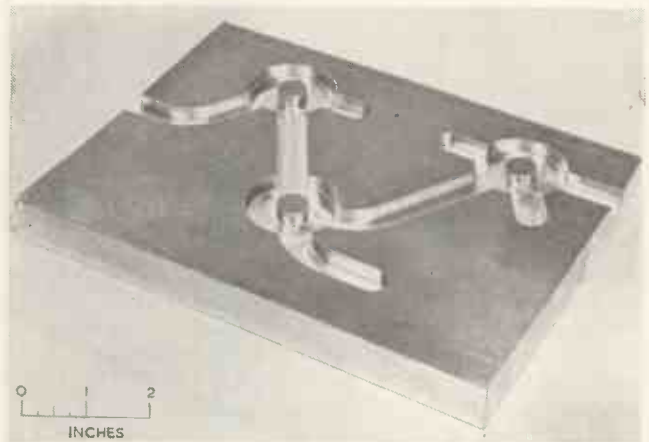


Fig. 6. A waveguide section machined on the vertical milling machine under electronic control

equal to the algebraic sum of the pulses on the x , y and z channels divided by four. Circuits are included in the machine control console which summate the pulses received from the x , y and z measuring systems on the machine tool and check that this algebraic sum divided by four compares with the pulse train on the fourth channel. Thus any fault such as tape damage, incorrect reading, or failure in the electrical circuits will be detected and protective gear actuated should the cumulative discrepancy exceed predetermined limits. This applies powerful brakes to all servomechanisms, stopping the slides instantly. This gives a high measure of protection in conjunction with error limit monitors on the register of each channel.

Example of Machined Component

An actual section of a complete waveguide unit machined by the vertical milling machine under electronic control is shown in Fig. 6. In this example, the machining is in two planes only. This section together with its opposite "hand" forms a waveguide ratrace unit.

The machining time for this section was 6 minutes. For hand controlled machining, the time required is approximately 16 hours for the same degree of accuracy.

A second magnetic tape is not required to machine the opposite section of the wave guide. The existing tape can be used with a sense reversal instruction programmed on the tape.

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Synthetic Music

By Alan Douglas, M.I.R.E.

The art of electronic music has recently been extended to research on the fundamentals of tone production and the influence of the non-tonal parameters—noise, phase-shift, vibrato etc— on the sound. From this work has developed circuits and apparatus capable of complete synthesis of musical instruments and the singing voice.

ONE of the insuperable difficulties encountered in the analysis of the tonal spectrum of musical instruments has been that by virtue of the mechanism of generation, there are many undesirable noises due to the application of the exciting force. These noises represent an excess of energy beyond that required to attain resonance, or application of the stimulus to some part of the instrument which is inactive tonally, and may be very objectionable. Sometimes the noise band is closely related to the tone band, in other cases it is separated by some octaves from the tone band. It is only the much larger tone output due to resonance which masks the noise in that range, but although filters can be used to remove noise outside the tone band, modulation due to that which remains affects the observed tonal spectrum and leads to erroneous analysis in many cases.

No physical instrument is free from such noises and common examples are, the thud of hammers on the piano: the scraping of bows on instruments of the viole family: the hiss of air in the flute: the plucking sound of harp, guitar etc.: the escape of wind in organ pipes. In existing instruments, these noises must be present if any tone is to be produced. This has hindered research on tonal development and reduces fidelity in broadcasting and recording. The necessity for dividing musical tones into the intervals of the equally tempered scale, forced upon us by the use of keyboard and wind valve instruments requiring rigidly fixed tonal intervals leads to many complications, because the true harmonic series of musical instruments does not correspond with the equally tempered intervals and these latter themselves are not equally concordant in any combination.

In the case of infinitely variable pitch instruments such as the viole family playing alone, this limitation need not apply and the superior quality of tone and exactness of tune of a string quartette is a good example of the advantages of tonal freedom.

There have been other systems for dividing the octave into equal parts, but only the equally tempered scaling allows freedom of modulation in all keys. Space does not permit analysis of the shortcomings of any fixed scaling system, but these are described in detail elsewhere¹. The fact is that in all systems, some intervals are objectionable and to make matters worse, different tuners work to different arbitrary limits according to their tonal sense.

The presence of instruments sounding even harmonics with others sounding odd harmonics leads to musical difficulties when the harmonic texture is closely interwoven within the same octave. This is a limitation to composers. An instance is shown in Fig. 1, taking an oboe (even harmonic series) and a clarinet (odd harmonic series). The dissonance due to beating of the upper partials is shown for two common musical intervals, from which it will be seen that reversing the pitch order of these instruments produces quite different effects.

The loudness and pitch range of all physical instruments is fairly well determined and an increase in either is only

obtainable by using more, or different, instruments. In many cases, the proportions of harmonics to fundamental radiated are very variable over the tone range, particularly at the extreme ends of the compass.

The "breadth" and fullness of tone associated with most forms of music requires a good acoustic environment which has (except for novelty effects) a reasonably well-defined desirable reverberation time for each class or group of instruments.

The foregoing, and other factors in tonal assessment, have led several investigators to examine the possibilities of synthesizing musical tones on a somewhat more extensive basis than has hitherto been the case. The joint objects of tonal analysis and adjustment of the temperament are naturally compatible in a method free from existing restrictions, and more recently, the work has been extended to cover the synthesizing of complete orchestras and even the voice.

In order to form a basis from which to work, all investigators have broken the tone down into its fundamental parameters. These are:—

- (1) Frequency (or pitch)
- (2) Level (or loudness)
- (3) Duration
- (4) Envelope control (rate of attack and decay)

and as second order requirements:—

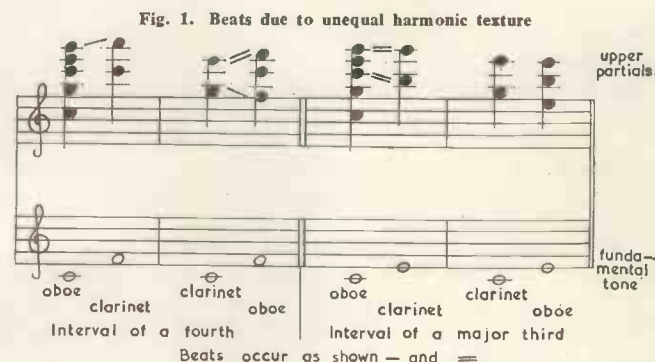
- (5) Vibrato
- (6) Reverberation
- (7) Phase control

and, for full synthesis,

- (8) Harmonic content (or timbre)

Any musical tone must embrace the first four constituents and most require some contribution from the other four.

A considerable number of investigators have worked along these lines²⁻⁶, most of which were propounded by Busoni⁷ in 1906, but since clearly such experiments must be costly and well-organized, it has remained for the University of Bonn and the Cologne studios of NWDR.



in Germany, and the Radio Corporation of America in the U.S.A. to produce positive results.

The fundamental approach is similar in both schools of thought, but the methods are quite different. In the German system, several operators are required, each of whom is a musician, and one of whom is a "mixer", which office can in this case be compared to that of a conductor. The resultant tones may be heard at the time of performing but they may also be stored on tapes or disks and re-recorded with further mixing.

The RCA apparatus prepares the constituents of the tone in advance in the form of a punched paper record, similar to that for a player piano, and the combined signals are automatically removed from this and synchronously recorded on disks. The "sound" is thus pre-formed and is in permanent form; subject, however, to further modification in re-recording, if required.

Both systems can form "new" tones and both can form any number of superimposed tones by re-recording. It is a curious coincidence that in both cases, only two notes at any one time can be produced by the system. Both methods can also produce gliding tones, manually in Germany, automatically in America. This is necessary, especially in an automatic system, to obtain portamento or the smooth transition from one note to another, characteristic of the strings and trombone. It might also be very desirable to apply this to tones where it is not normally possible.

Although noise was cited as a defect in conventional tone production, controlled noise can be introduced to extend this spectrum in some cases and is necessary if, for example, a synthetic cymbal was required. Both systems have a noise generator.

It is evident that the German approach is flexible and can be stepless, but is not repetitive with an accuracy greater than the judgment of those operating the system. The RCA method is divided into a certain number of steps but since these are controlled by geometrically related registration from a synchronized coding system, the accuracy of reproduction is invariable.

As the German system is perhaps the simpler of the two, it will be described first. In both cases, it was mentioned that two notes could be simultaneously generated, but the path of one note suffices to illustrate the system. Any prime frequency source used should be capable of infinite frequency variation. Key controlled tone sources can be used, but to fully exploit the method the Trautonium is the principal source. This instrument is a sawtooth thyatron oscillator in which the frequency is controlled by variation of the grid bias. To accomplish this over a range of $3\frac{1}{2}$ to 4 octaves with a reasonably compact control element, the biasing resistor is wound round an elliptical former about 36in long. This is surrounded by a springy metal gauze cylinder which can be compressed to contact the resistor as required, and dummy rubber keys are mounted above to indicate the main intervals. Depression of the resistance element compresses a flexible tube containing a liquid resistance, and this allows the signal to pass. It is in fact a touch-responsive system. The basic elements of the Trautonium (for this purpose) are shown in Fig. 2. Other more elaborate models of the instrument are made.

The sawtooth wave contains properly related even and odd harmonics and therefore, musical tones can be formed therefrom. It is notable that both the German and American methods provide a complex wave for each frequency source and do not use an additive method to form tones, in which sine wave generators would be combined as required. A subtractive method of tone forming leads

to a great reduction in the complexity of the apparatus since the higher harmonics are already present in the generated waveform and it is not necessary to attain quite as exact a frequency stability.

To follow the development of the system better, in Fig. 3. is shown an example of a musical notation experimentally derived for this kind of work. It can be seen that this is a score suitable for direct performance of monophonic music as well as for the formation of synthetic tone colours. At first sight it appears rather complicated, but it is really very logical. For the first time in musical history, it shows all the actual constituents of a tone. This example is purely hypothetical, but a somewhat similar construction is in use.

The frequency range is indicated on the treble staff. This is marked 1 to 10 and normally refers to a pitch range of

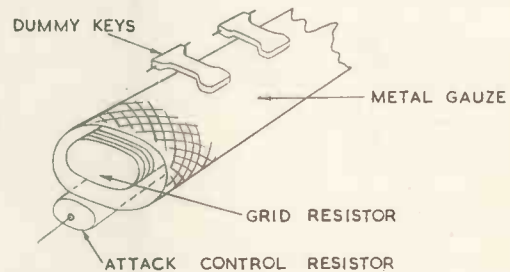


Fig. 2. Keying elements of Trautonium

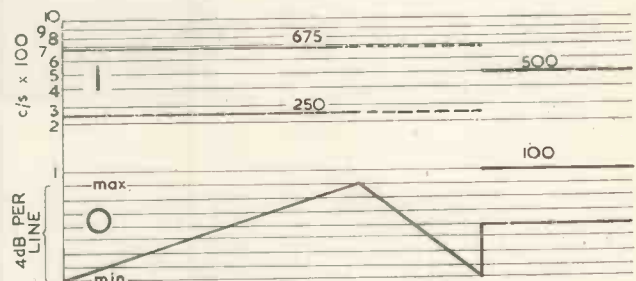


Fig. 3. Experimental notation

from 100 to 1000c/s. Should it be necessary to raise the pitch or frequency, a figure is inserted where the key signature would ordinarily be; if this figure is 1, the frequency range is as above; if 2, it becomes 200 to 2000c/s, and so on. Lower ranges are denoted by fractions, e.g., $\frac{1}{2}$ would be 50 to 100c/s. The actual frequency may of course not lie on a line, it is then written in between. The duration or tempo must be known in advance, and this is usually related to an approved tape speed, commonly 76.2cm/sec. The level is indicated on the bass staff, the shape or slope of this showing how it is to be applied. Each line here represents a 4dB change. A tone sustained by artificial reverberation may be shown continued dotted. Additional instructions can be inserted in the space between the staves. The mixer may also have still further symbols so that he can maintain the correct perspective, which is necessary as several operators are feeding him with signals.

Fig. 4. shows an arrangement of a Trautonium tone source as one prime constituent of the mixing system. It will be seen that there are a number of auxiliary tone and modulating circuits associated with the fundamental generator, and still more can be added.

Another tone source used in some of these experiments is the Bode Melochord. This is a keyboard instrument and contains a very elaborate filter or tone forming system.

It is a multivibrator generator and the tone outlets are capable of all the external modulations which can be applied to the Trautonium. The compass of the keyboards is three octaves. A block diagram of the connexions is shown in Fig. 5.

Fig. 6. shows a complete tone forming and mixing system, one of a number of possible alternatives. The final mixer can introduce any of the effects as required and these also include vibrato: noise: reverberation: ring modulator harmonic control: external filter and other shaping elements. The circuit of a noise generator is shown in Fig. 7.

It is evident that by having sufficient operators and tone sources, synthesis of most known tones can be effectively

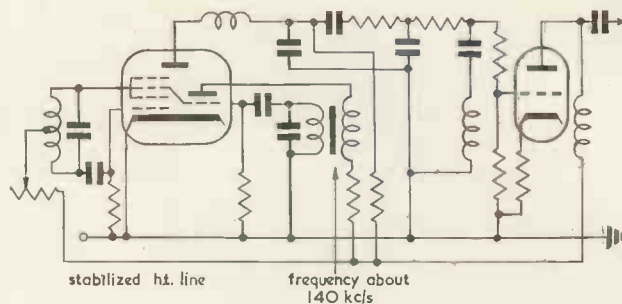


Fig. 7. Noise generator

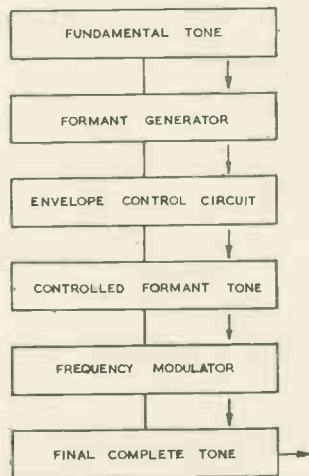


Fig. 4. Tone build-up in the Trautonium



Fig. 8. General view of apparatus for electronic music

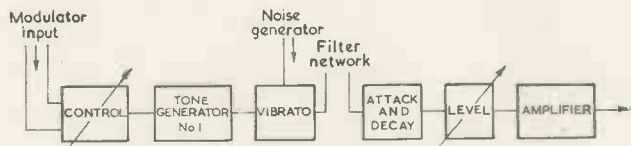
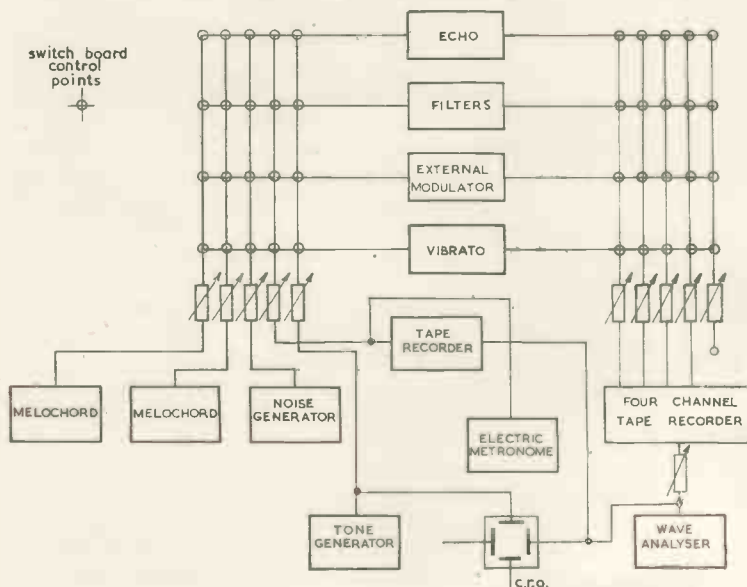


Fig. 5. Schematic diagram of Melochord

Fig. 6. General arrangement of a tonal analyser



produced, recorded and studied. It also means that artificially compounded music can be played at once, and in fact a number of broadcasts have taken place. The type and character of the music is immaterial; this is not necessarily an apparatus for the modern composer. But it does permit of an extension to the pitch and dynamic range as ordinarily understood and it must therefore be a help to composers who have had to limit their imagination because they outpaced the capabilities of conventional instruments.

Such a system is well suited to the needs of research workers with, in addition, the ability to act as an instrument of performance. An illustration of the apparatus in use at the Cologne studios of NWDR is shown in Fig. 8.

Turning now to the American system, as developed by RCA under the direction of Dr. H. F. Olson, we observe a greater trend towards "automation". Basically the same fundamental parameters for a tone are set up, as indeed they must be. There are many radical differences in the methods used. Everything originates in a punched code record which is driven synchronously with a disk recorder capable of recording several channels simultaneously but as independent bands on the disk.

Each source for one constituent of the final tone is allotted a strip on the code record. On this strip are punched, by hand and in advance, holes corresponding to the quantity and duration of the component. If, for example, one fixed frequency is to start and persist for some

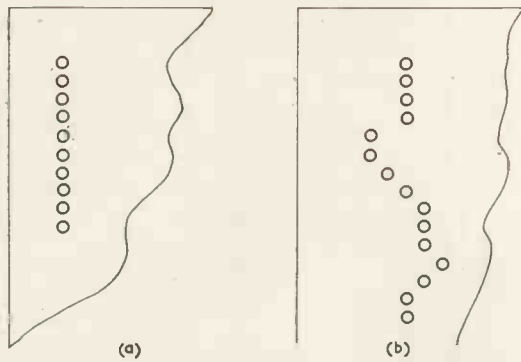


Fig 9(a) and (b). Punchings for single note and moving notes

known time, (obtained from the driving speed and hole diameter), then a series of holes would be made as in Fig. 9(a). Contact is made through the holes to a number by flexible brushes, and these are so designed that a fresh hole (if there is one) is contacted before the circuit is broken at the previous one. In this way, the tone continues unbroken. Should the frequency change, as in playing a melody, then the holes are punched to contact the proper brushes, as in Fig. 9(b). The level, timbre, vibrato and portamento controls are similarly perforated in their respective sections of the paper record, so that all constituents are scanned by the brushes as the roll moves. Fig. 9(c) shows a part of a record, reproduced with acknowledgment to the Journal of the Acoustical Society of America, of a few notes from "Home Sweet Home". Part is recorded on channel 1 and part on channel 2.

The summed parameters of the tone are passed to a recording head where they are impressed on a disk record. From the separately treated recorded bands, further recordings are made until the whole of the subject is completed on a single disk.

The RCA system uses twelve tuning forks as the prime

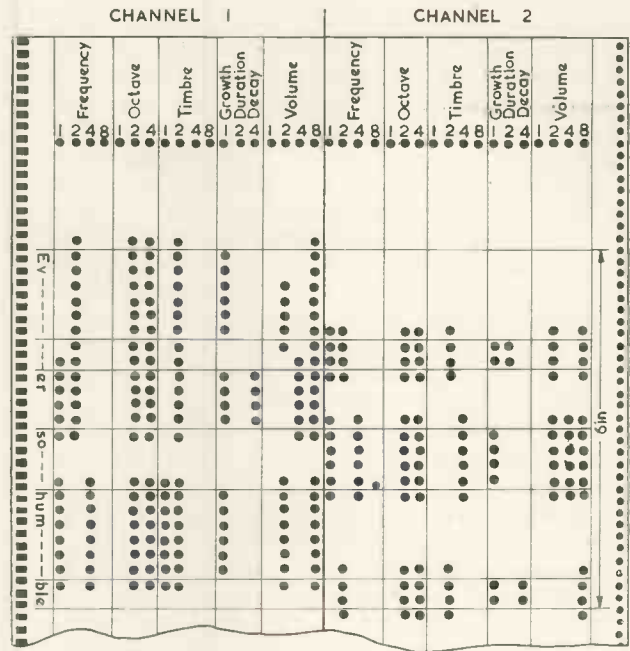
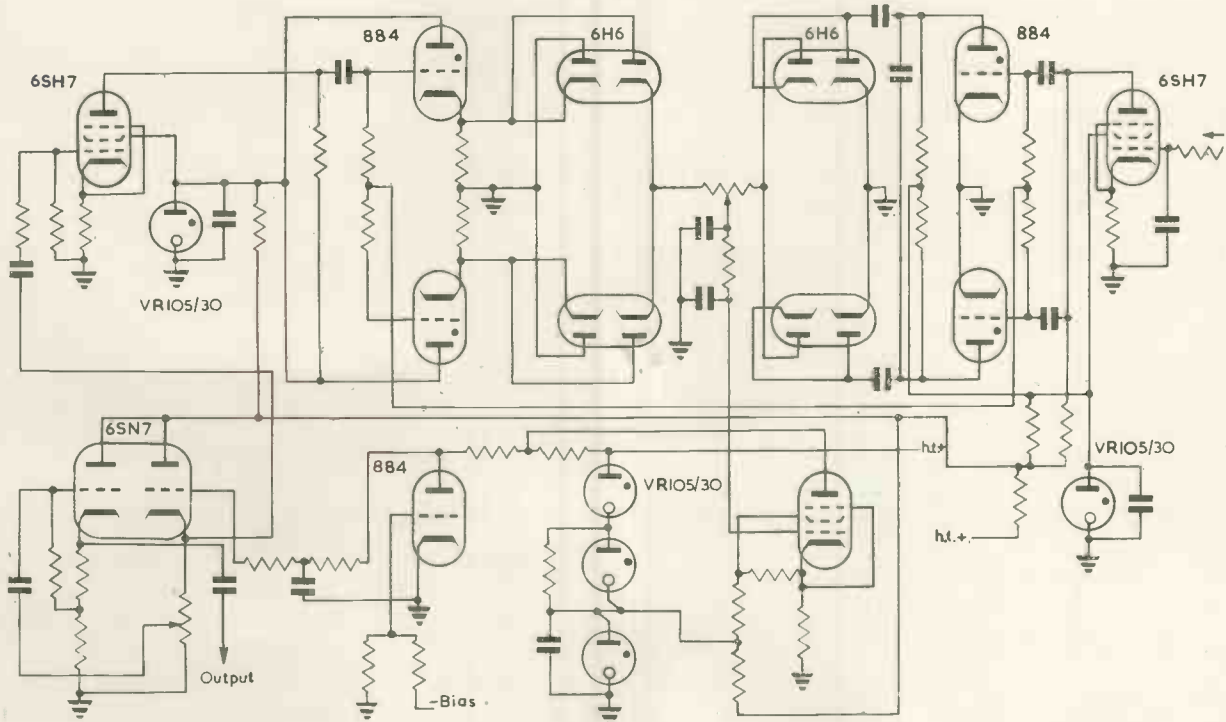


Fig. 9(c). Part of actual code record

frequency sources, the required pitch range being obtained by frequency division and multiplication. Each output has a shaping circuit to provide a full harmonic series for each frequency. Elaborate filters are provided for tone forming and a particularly interesting circuit is that used for the automatic portamento—or glissando in a more extreme

Fig. 10. Automatic frequency glide circuit



form, eg. the Hawaiian guitar. This is shown in Fig. 10. The input signal pulses are passed through an integrator and low-pass filter. The resultant direct current is amplified and supplied to an oscillator of which the frequency is a function of the d.c. input. The output drives a pulse generator, the polarity of which is the opposite of that of the input signal pulse. It is a comparison system in which the frequency of the oscillator adjusts itself to the input frequency; should this change in a discontinuous way, as for example in passing from one note to the next on a keyboard, the oscillator will change in sympathy but in a continuous manner without any manual control. Means are provided to alter the rate and envelope of the gliding circuit for special purposes. All of these may be operated by additional coded signals from the paper strip.

Due to the necessity for fully automatic and synchronous operation the complete apparatus is very complex, and a photograph of this together with a much more detailed description will be found in the May issue of the Journal of the Acoustical Society of America, 1955. The powers of synthesis are almost limitless and it has even been possible to record a synthetic singing voice with synthetic

orchestral accompaniment which apparently deceived at least 50 per cent of listeners.

Considerable credit is due to the instigators of these researches. Dr. W. Meyer-Eppler in Germany and Dr. H. F. Olson in America. The fact that responsible organizations are prepared to spend so much time and money on this kind of research underlines the importance of electronic music in no uncertain way, and the impact of this art may be far reaching indeed.

The author is particularly grateful to Drs. Meyer-Eppler and Olson for information received, and wishes to acknowledge Figs. 3,4,5,6,7,8 to the Technische Hausmitteilungen, NWDR; and Figs. 9(c) and 10 to Dr. Olson and the Journal of the Acoustical Society of America.

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Principles and Application of Electronic Analogue Computers

(Part 3)

By P. Heggs*, A.M.I.E.E.

In this part design considerations apertaining to two computer units will be discussed, followed by a consideration of the complete computer.

Operational Amplifiers for Summation and Integration

These as previously stated are high gain d.c. amplifiers whose internal gain may vary between 200 times to 2×10^7 at d.c. if automatic drift correction is employed. In the drift corrected amplifier the major portion of the frequency range will, however, be much lower than 2×10^7 , values of 20 000 to 100 000 being quite common, falling by 3dB at 1kc/s.

When used as summation amplifiers a useful design criterion is that with the maximum number of inputs likely to be employed, and using the maximum value of external gain (determined by the input and output resistances), the summation error will not exceed 0.1 per cent. This figure then determines the required internal gain.

For example, a similar calculation to the one in Part 2 for the output of a summation amplifier applied to Fig. 16 yields:

$$e_o = -[(e_1/R_1) + (e_2/R_2) + (e_3/R_3)] \cdot \frac{A}{(A + 1) + [(R_o/R_1) + (R_o/R_2) + (R_o/R_3)]} \dots \dots \dots (12)$$

* Canadian Westinghouse Co. Ltd, formerly Saunders-Roe Ltd.

which in the general case for n inputs becomes:

$$e_o = -R_o \sum_{i=1}^n (e_i/R_i) \frac{A}{(A + 1) + R_o \sum_{i=1}^n (1/R_i)} \dots \dots (13)$$

Now as $A \rightarrow \infty$ the output becomes:

$$e_o = -R_o \sum_{i=1}^n (e_i/R_i) \dots \dots \dots (14)$$

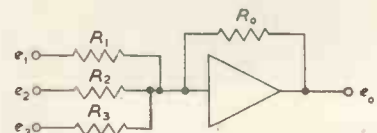


Fig. 16. Amplifier used for summation

thus the percentage summation error due to use of finite gain, equation (12) and (13) becomes:

$$\epsilon = (100/A) (1 + R_o \sum_{i=1}^n (1/R_i))$$

If a criterion of $\epsilon = 0.1$, i.e. a 0.1 per cent summation error, then to achieve this the internal gain A must be

greater than $10^3(1 + R_o \sum_{i=1}^n (1/R_i))$. For some applications

lower internal gains with correspondingly higher errors may be tolerated, but computers may contain upwards of 50 or more amplifiers when complex systems are under solution. It is quite impossible to calculate the error in the final answer for such systems, and the best that can be said is that the computer is solving a system whose coefficients do not differ by more than a given percentage from the actual system.

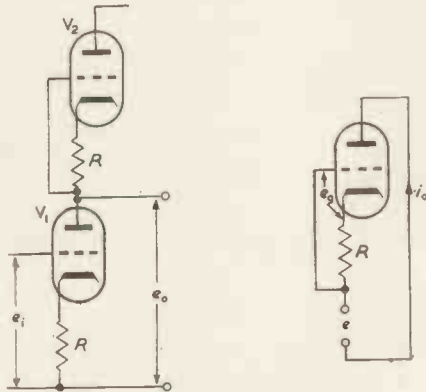


Fig. 17. Series compensator input stage

Fig. 18. Anode load circuit for V1 in Fig. 16

Amplifier Input Stages

The input stage influences the accuracy of the amplifier, and hence drift, grid current and noise should be kept low.

A large proportion of amplifier drift is due to filament voltage variations. The effect of this may be minimized by drift correction, which introduces a counter-voltage into the amplifier of opposite polarity to the drift, or by an arrangement known as "series compensation" which consists of two identical input valves in series, such a combination being theoretically independent of the valve parameters apart from the amplification factor.

This can be shown as follows. In Fig. 17 if μ , r_a and g_m are the valve constants. Then applying the anode circuit theorem to V_2 as in Fig. 18.

$$i_a = \frac{\mu e_g + E_a}{R_a} \dots \dots \dots (15)$$

where e is the voltage applied in series from V_1 .

Other symbols have their usual meanings and voltages and currents are read as increments, but $e_g = i_a R$ and $E_a = -i_a R_L + e$.

Substitution in equation (15) gives the impedance at the points (1) and (2) as:

$$Z = (e/i_a) = r_a + R(\mu + 1) \dots \dots \dots (16)$$

Using this impedance as an anode load for V_1 in Fig. 17 and reapplying equation (15) gives:

$$i_a r_a = \mu (e_i - i_a R) + E_a \dots \dots \dots (17)$$

but $E_a = -i_a R_L$. R_L is the load resistance for V_1 and equal to Z from equation (15).

Substitution of these values in equation (17) and using the relation $e_o = i_a Z$ gives, after simplification:

$$(e_o/e_i) = -(\mu/2) \dots \dots \dots (18)$$

which is independent of valve parameters providing each valve varies in the same manner.

The Drift Corrected Input Stage

In this circuit use is made of a subsidiary a.c. amplifier to amplify the drift signal and re-apply this in anti-phase to the input stage. This technique slightly modifies the response of the amplifier due to time-constants $C_1 R_1$, $C_2 R_2$. Due to the very large zero frequency gain of the combination low frequency summation errors are greatly reduced.

In Fig. 19 the system consists of a conventional d.c. amplifier having a gain A_1 together with an a.c. amplifier, the input of which is modulated by a relay or chopper, which alternately earths the input and output of the ampli-

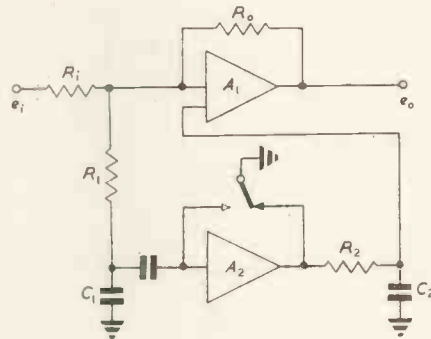


Fig. 19. Drift correction of a d.c. amplifier

fier A_2 . This chopper may be excited at frequencies from 50 to 400c/s in which case the carrier frequency of the a.c. amplifier is 100 to 800c/s.

The time-constant $R_1 C_1$ is made equal or greater than 0.15sec, while the output time-constant $R_2 C_2$ is the order of 10sec.

The basic circuit of this type of amplifier is shown in Fig. 20. Values of A_1 and A_2 may be from 2×10^4 to 10^5 and 2×10^2 and 1.5×10^3 respectively giving maximum values of d.c. gains of 1.5×10^6 .

The reduction in equivalent drift voltage at the grid of the input stage is directly proportional to the gain of the a.c. amplifier, provided that the modulator relay itself introduces no drift at its contacts. All relays introduce some drift and contact potentials however. The use of both stabilized heater and h.t. supplies enables an effective drift at the input grid of less than 1.5mV to be maintained for long periods using the Siemens H96D relay, feeding an a.c. amplifier with a gain of 200 times.

Stabilization of computer amplifiers follows the normal process of ensuring that the phase amplitude locus of the open loop amplifier transfer function does not enclose the point $-1, 0j$ or, stated another way, for the frequency at which the phase shift is -180° the loop gain must be less than unity, otherwise sustained oscillation will result.

Power Supplies

D.C. analogue computers require a minimum of five separate power supplies. These are a positive and a negative supply for operation of the main computing units, a negative supply about twice the voltage of the main supply, to supply offset bias for the d.c. amplifiers, a low voltage d.c. supply for operation of function relays, together with a.c. or d.c. supplies for operation of valve heaters.

All of the above power units require to be regulated and

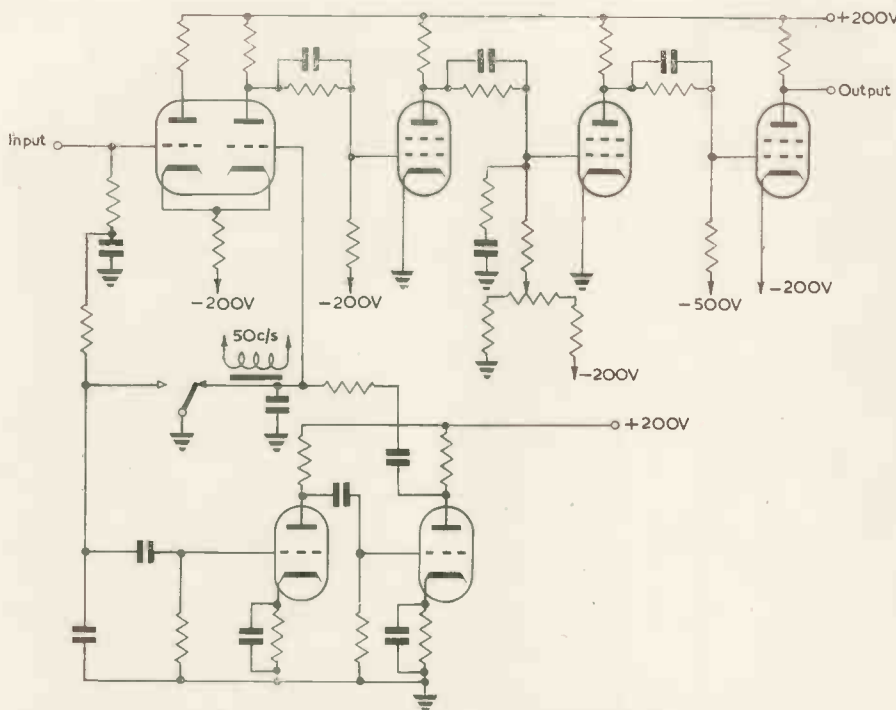


Fig. 20. Basic circuit of a drift corrected d.c. amplifier

have low internal impedances, with the exception of the relay supply.

The main positive and negative supplies are usually between $\pm 200V$ and $\pm 350V$, respectively, depending on the output required from the operational units, while bias supplies will be between 400 and 600V negative. As there are many operational units it is desirable to limit the power consumption as much as possible, and $\pm 200V$ for the main supply units is a reasonable figure, when it is considered that the total h.t. current may be from 2 to 3A for a medium sized computer. Large installations can take up to 5 or 6A.

Some idea of the stability required of the power supplies can be obtained from the following figures.

A computer amplifier consisting of a main amplifier of gain 10^5 , and a drift correction amplifier of gain 200, when operating at unity gain had an effective output change of 1mV for a supply change of 1V in $\pm 200V$. A 10V change in the $-500V$ bias supply gave negligible difference in output.

On the other hand a sign reversing amplifier of internal gain 2 000, incorporating a series compensating input stage had an output change of 25mV or a change of 1V in either of the 200V supply units and 50mV change for a 1V variation in the 500V negative bias supply.

From the above figures it is obvious that if drift corrected amplifiers are to be used throughout, the power supplies for these need not be as highly stabilized as those supplying circuits which do not admit of drift correction.

On the other hand if all power supplies are designed with an order of stability much higher than the minimum, they may be taken as adequate for any apparatus they may be called upon to operate.

This policy was adopted in one

medium sized analogue computer, whose supplies were distributed by $\frac{1}{4}$ in diameter bus bars. The power units coupled to these bars had output impedances of 0.02Ω , while the bus bars themselves had resistances of 0.02Ω between the supply and the feed points to a bank of amplifiers.

TYPES OF STABILIZED POWER SUPPLY

While single phase a.c. supplies are adequate for medium sized computers, three phase rectification may be advantageously employed in a large installation, with consequent saving of weight in transformers and smoothing equipment.

Since the total h.t. current for the positive and negative supplies is large, a number of series valves are required with consequent large dissipation of power.

Further, since in the conventional series valve stabilizer, the valves are called upon to pass a constant current under widely

varying conditions of mains input voltage, more series valves are required than if the input voltage to the series valves remained sensibly constant.

For example, using valves of the EL37 class a reduction from 20 to 13 valves may be made for a current of 2A if a constant supply voltage is available.

One method of achieving this is by means of thyratrons used as regulated rectifiers. This system can be made to have an internal impedance of 10Ω or less for a one ampere unit. Two such units feeding a bank of six A1834 (6AS7) regulator valves preceded by two amplifier stages have an internal impedance of approximately 0.02Ω .

It is, however, high power stabilized supplies of the order of 6A d.c. where the thyatron pre-regulator really comes into its own. The ancillary control equipment needed to operate any thyatron is the same whatever the valve capacity, while a series valve saving of 35 per cent is achieved.

The block diagram of pre-regulator and stabilizer is shown in Fig. 21.

A full description of this circuit will be given in a later article. Briefly the thyatron output after smoothing is fed to a comparison circuit, the error voltage from which is modulated at supply frequency by a polarized relay. The

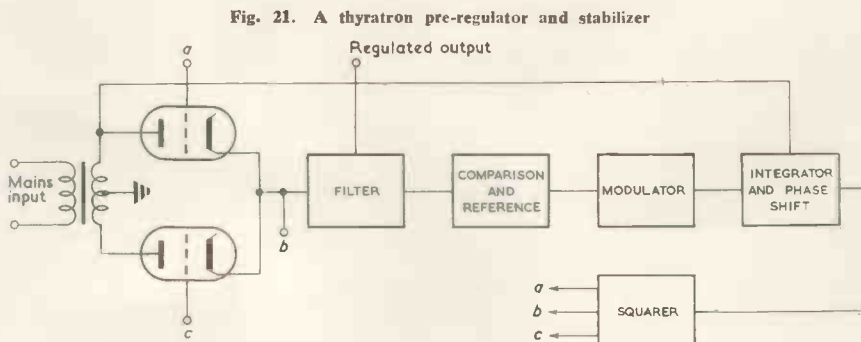


Fig. 21. A thyatron pre-regulator and stabilizer

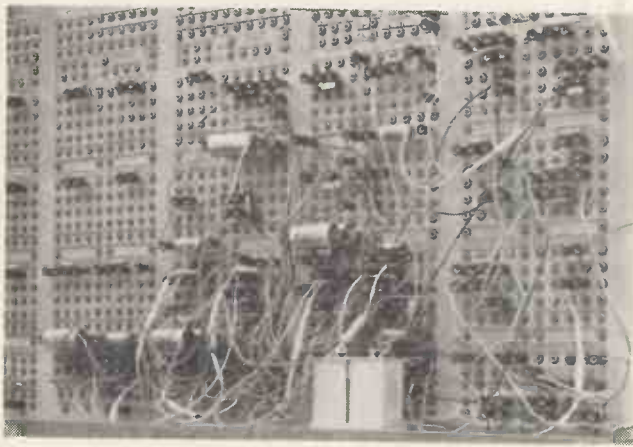


Fig. 22. Patch panel of the Saunders-Roe general purpose analogue computer

square wave is integrated and combined with a suitable mains reference derived from the secondary of the power transformer. This composite waveform after squaring is applied to the grids of the thyatron rectifiers.

The Complete Computer Installation

The size of a complete computer installation is governed entirely by the numbers and types of differential equations required to be solved simultaneously. Assuming that each amplifier is capable of giving outputs of either sign, then if there are m equations whose highest derivative is n , then $m(m + 1)$ operational amplifiers will be required to solve the system and allow recording of the highest derivative. If the latter facility is not required, then $m \times n$ amplifiers will be required. Any derivative multiplied by a variable coefficient will require a multiplier, as will a squared quantity, while cubed quantities will require two multipliers. In addition a limiter unit will be needed for each discontinuity to be introduced.

The number of coefficients in the system determines the number of potentiometers needed but the type of potentiometer used depends on the accuracy of setting specified. For example, if a resolution of 0.1 per cent is required, then a 10-turn helical potentiometer is imperative, but for quantities requiring a setting accuracy of 1 per cent, high grade single-turn potentiometers may be used, and set up by external means.

A very important feature of any analogue computer is

its inter-connexion panel. In general inter-connecting leads require to be short and neatly arranged if a problem is to allow of ease of "reading" on the machine and in addition the inputs and outputs of the various units require to be clearly labelled.

Much time can be spent in checking problems if the above conditions are not met.

If all leads are run from the computer to a separate console containing recorders and controls, the use of repetitive operation is precluded due to the long connexions giving crosstalk, and further, the identity of the problem under solution is completely obscured.

If when a computer is projected the final size is known, then a central connexion panel to which all units are connected will generally permit short enough lead lengths for low frequency repetitive operation. This method is illustrated in the patch panel (Fig. 22) of the Saunders-Roe general purpose analogue computer. This machine was designed to solve general dynamic and mathematical problems, but in addition an over-riding factor was that it should be capable of solving the six degree of freedom aircraft flutter equations.

This problem calls for thirty amplifiers, five per degree of freedom, together with one hundred and eighty flutter coefficient potentiometers capable of being set with an error of less than 1 per cent. In addition eighteen of these coefficients had to be varied simultaneously, and this was achieved by mechanical ganging.

On the other hand, if the final size is unknown at the outset, as may be the case in many installations, then a recommended method is to connect the units in each rack of equipment to a patch panel and continue this panel from rack to rack as each addition to the machine takes place.

This system allows of extension with the minimum of alterations to a machine already in proven service. A suggested scheme is shown in Fig. 23. As the machine is extended the inclusion of an operator's desk is desirable with recording equipment built above it, together with those controls that need to be most frequently operated.

Circuit Constants

As has been seen in previous articles, a number of resistors and capacitors are associated with the operational amplifiers. These may be located either in special units known as function units, in the amplifiers themselves, or they may be plugged directly into the patch panel.

The best method appears to be the last mentioned and has the following advantages.

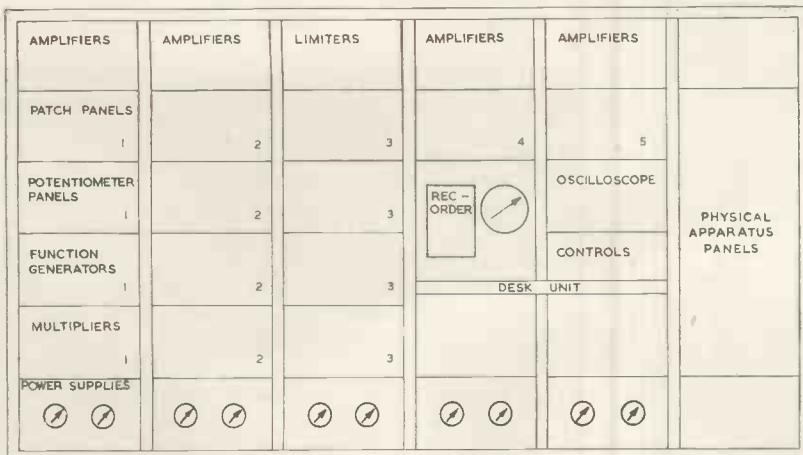
These components, which are always of close tolerance and high stability are kept in a fairly uniform temperature, being outside the racking. The method does not immobilize a large number of relatively expensive items, and the actual components in use may be seen at a glance.

Inclusion of Physical Apparatus

Many problems will require the inclusion of auxiliary physical apparatus such as aircraft auto pilots, electrical pick-offs and gyroscopes. In order to accommodate apparatus of this nature, space may be conveniently left in the racks for stowage—with appropriate power supplies run to allow ease of connexion.

(To be continued)

Fig. 23. One suggested layout for a flexible analogue computer



The Design of Phase-Shift Oscillators and Filters

By J. C. Shaw*, B.Sc.

This article describes a single valve low frequency filter with a tapered three-mesh CR network in a positive feedback path. Negative feedback over the valve gives stability. Curves are given comparing the attenuation of the CR network for various input-output impedance ratios and tapering factors with those of the equal element case and minimum attenuation case.

THE phase-shift oscillator employing a ladder network in the positive feedback path of an amplifier has long been recognized as a simple and convenient form of oscillator, particularly at low frequencies^{1,2,3,4,5} (Fig. 1(a)). If the gain of the amplifier is insufficient to overcome the attenuation in the ladder network, the circuit will not oscillate but will act as a filter whose selectivity depends on the amplifier gain and whose "resonant" frequency f_0 is determined by the same factors which determine the frequency of the oscillator.

When used as an oscillator or filter the resonant frequency of this circuit is dependent on the output impedance of the amplifier feeding the ladder network. When used as a filter the selectivity is determined by the amplifier gain and the attenuation in the feedback path. The losses which the amplifier has to make up for a given selectivity are again dependent on the output impedance of the amplifier and also by its input impedance since R_3 (Fig. 1) will consist of the final element of the ladder in parallel with this input impedance. This dependence is best determined in terms of the ratio of amplifier output to the equivalent input impedance, i.e. the ratio $R_0:R_3$ in Fig. 1(b), which shows the equivalent circuit for determining the attenuation in the feedback path. Thus the design of this type of circuit requires consideration of (i) the stability of amplifier gain, (ii) the stability of amplifier output impedance, and (iii) the stability of the ratio $R_0:R_3$.

One of the advantages of this circuit is the fact that it may be designed around a single valve amplifier; for example this is convenient in a wave analyser using a large number of filters of this type⁵. With a single valve, however, the above factors are more difficult to control.

It is usual to employ three CR meshes as in Fig. 1, and this is sufficient although more elements may be used. RC elements may also be employed but will not be considered here because the former are more suitable for low frequencies. At high frequencies other factors are involved⁶. Considering the equivalent circuit of Fig. 1(b) the simplest network has $R_1 = R_2 = R_3$ and $C_1 = C_2 = C_3$. The attenuation may be reduced by tapering the elements by a simple ratio so that the loading of successive elements on previous elements is reduced³, i.e. we make $R_3 = aR_2 = a^2R_1$; $C_3 = C_2/a = C_1/a^2$. Ward⁴ has calculated the relationship between the elements for minimum possible attenuation which involves a more complex relationship between the elements.

When taking the amplifier output impedance into account the most convenient form of data required for design is that given by Ward for the minimum attenuation network. Townsend⁷ and Tissington⁸ give similar information for the equal element circuit, but other authors tend to neglect the effect of source impedance^{1,3}. Sultzer³, for instance, assumed this factor negligible when considering the tapered network which is probably the most practical type of network to use in a wave analyser employing many filter units. In Fig. 2 the attenuation of the tapered network with

various tapering factors for various ratios $R_0:R_3$ is shown for comparison with the equal element circuit and Ward's minimum attenuation circuit. This illustrates three important points. Firstly, the tapered networks approach

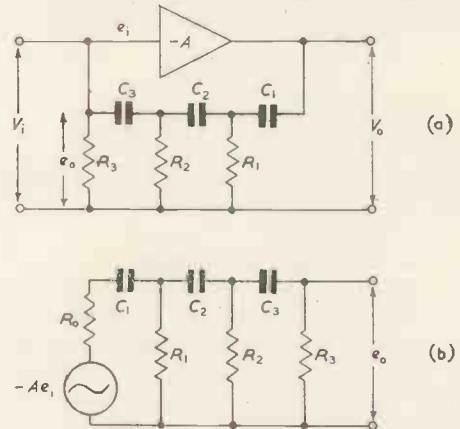


Fig. 1(a). Basic oscillator or filter circuit employing three mesh CR ladder network

(b). Equivalent circuit for analysis of three mesh CR ladder network

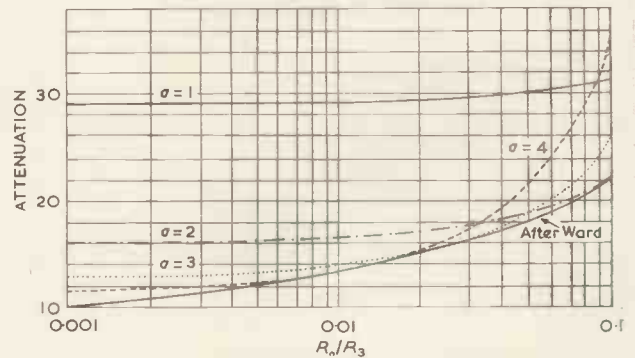


Fig. 2. Attenuation in network of Fig. 1(b) $R_3 = aR_2 = a^2R_1$; $C_3 = C_2/a = C_1/a^2$, with $a = 1, 2, 3$ and 4 compared with Ward's minimum attenuation network.

the ideal network over a limited range of $R_0:R_3$ depending on the tapering factor. Secondly, the networks have a range over which the attenuation is little affected by changes of $R_0:R_3$ but this requires this ratio to be very small. Thirdly, with $R_0:R_3$ fixed the apparent advantage of an increased tapering factor is lost when the driving generator impedance becomes of the same order as the first element of the ladder. For example, if $R_0:R_3 = 0.05$ we see that the circuit with $a = 4$ gives greater attenuation than the circuit with $a = 2$ or 3. If $R_3 = 1\text{M}\Omega$ then $R_0 = 50\text{k}\Omega$ and for $a = 4$, $R_1 = 62.5\text{k}\Omega$; whereas with $a = 3$, $R_1 = 111\text{k}\Omega$.

The design of the single valve filter circuit to give stability of amplification is best carried out by using negative feedback over the valve. This may conveniently be obtained by using a large unbypassed cathode resistor. The negative

* Graylingwell Hospital, Chichester.

feedback is then current controlled and has the effect of increasing the r_a of the valve by $(\mu + 1) R_o$. Thus the load resistor has such a large effective resistance in parallel with it that the amplifier output impedance is determined almost solely by the load resistance and is less dependent on changes in valve r_a giving stability of R_o . The voltage drop in the cathode resistor will usually be larger than the required grid bias for the valve and this necessitates returning the grid leak to a suitable positive voltage. An alternative method is to return the grid leak to a tapping on the cathode resistor. This has the advantage of making the effective input impedance of the valve much larger than the value of the grid leak. There is the disadvantage, however, that the source feeding the signal to the amplifier must have an internal impedance small compared with the value of the grid leak if full advantage is to be obtained from the cathode resistor feedback. The effective internal impedance of the ladder network as seen by the valve grid is large and would require the use of grid leak resistors of prohibitively large values unless special low grid current valves were used.

The increased stability resulting from negative feedback in a valve amplifier is roughly proportional to the ratio of gain without feedback to gain with feedback. In this case the gain without feedback is equivalent to that obtained with the cathode resistor bypassed. It is then apparent that the requirement of a small output impedance (small anode load) is contradictory to the requirement of large gain when there is no feedback (large anode load). A compromise in these factors is therefore necessary. For a single valve circuit the input impedance will also be affected by the method of feeding the filter with a signal. These considerations suggest that a pentode valve has the advantage over a triode in giving a larger gain without feedback and a larger effective r_a with current controlled feedback. However, in designing this circuit with a pentode valve it must be remembered that R_o is in the screen cathode circuit resulting in a further reduction of gain.

In modifying a wave analyser employing a large number of this type of filter⁵ the author found that $R_o:R_s$ could not advantageously be made less than 0.1 with the available power supply restrictions and filter input circuit. From Fig. 2 it is seen that with this restriction the best results are obtained with a minimum attenuation circuit or a tapered network with a tapered factor of 2. The latter was chosen as the more practical of the two because each filter could employ capacitors having the value required for the second capacitor element, the first element having two of these in parallel and the third element having two in series. Also similar capacitor values occur in units for frequencies having an integral ratio. For $R_o:R_s$ of 0.1 a tapered network with tapering factor of 2 has an attenuation ratio of 22.28. This is the gain required in the valve to give oscillation. Using the circuit as a filter the gain required for various degrees of selectivity is shown in

Fig. 3. In curve A the gain required for the response at a frequency f to fall to 44 per cent of that of the resonant frequency f_o is plotted against the ratio $f_o:f$. The curve B shows in a similar way the gain required for a fall in response at f of 30 per cent. A practical circuit with

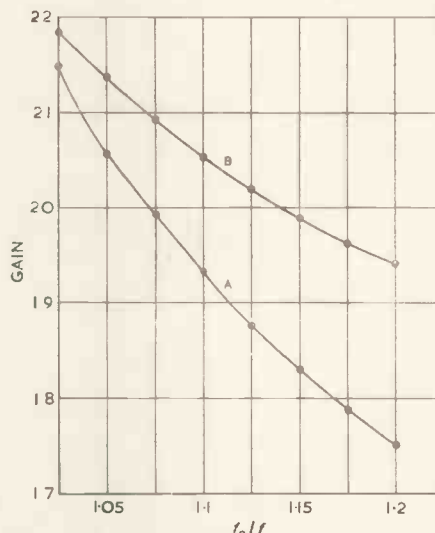


Fig. 3. Amplifier gain for given selectivity
Curve A: response at f 44 per cent of that at f_o .
Curve B: response at f 30 per cent of that at f_o .

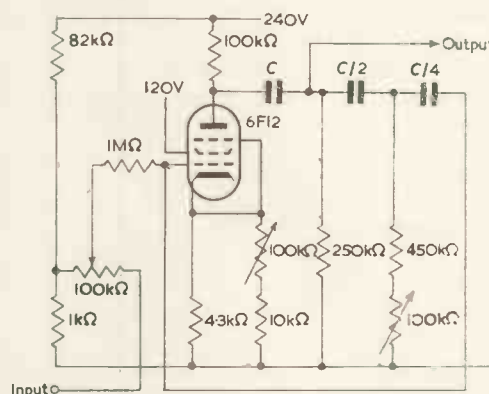


Fig. 4. Practical filter circuit

frequency and selectivity controls is shown in Fig. 4. Typical measured figures for selectivity are shown in Table 1. The effect of reducing the anode and screen supply by 10 per cent is also shown together with figures illustrating the effect of reducing the filament voltage from 6.3V to 5.6V in addition to the above changes. In Table 2 is shown

TABLE 1

Measured selectivity showing output voltage of circuit of Fig. 4 tuned to 15c/s.

f (c/s)	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0
As tuned (V)	0.59	0.75	1.15	1.92	4.10	1.90	1.19	0.80	0.62
H.T.—10% (V)	0.58	0.74	1.10	1.95	4.03	1.82	1.20	0.81	0.64
Plus L.T.—10% (V)	0.56	0.72	1.05	1.6	3.55	2.1	1.275	0.845	0.664

TABLE 2

Effect of replacing valve without re-tuning circuit.

f (c/s)	13.0	13.5	14.0	14.5	15.0	15.5	16.0	16.5	17.0
As tuned (V)	0.55	0.70	1.05	1.73	4.05	1.75	1.06	0.72	0.56
Valve No. 2 (V)	0.53	0.66	1.00	1.65	4.10	1.86	1.15	0.77	0.59
Valve No. 3 (V)	0.55	0.70	1.08	1.75	3.99	1.76	1.12	0.75	0.59

the effect of replacing the valve with two others chosen at random without any adjustment being made to the circuit.

The author has found the matrix method as described by Hinton² the most suitable for analysing this circuit. Referring to Fig. 1(b) for the tapered network analysis gives:—

$$Ae_1/e_0 = 1 - (X^2/R_1^2)(3 + 2/a + R_0/R_1) + \\ R_0/R_1(1 + (1/a) + (1/a^2)) \\ - j(X/R_1)[(3 + (2/a) + (1/a^2)) + 2 R_0/R_1 \\ (1 + (1/a) - (X^2/R_1^2))]$$

where $X = (1/\omega C)$.

The frequency is found by equating the imaginary part to zero.

This article was prepared some months ago and since

that time several related articles has been published which are not referred to here.

Acknowledgments

The author would like to express thanks to Dr. Martin Roth, Director of Clinical Research, Graylingwell Hospital, for permission to publish this article.

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New Barium Titanate Transducers

The Research Laboratories of the General Electric Co. Ltd, have now developed miniature barium titanate accelerometers and strain gauges which are proving extremely useful in the field of vibration testing. They have many advantages over older methods of vibration detection and measurement. They are inexpensive, reliable and simple to operate, and their very small size enables them to be used in a variety of circumstances where it would be impossible to accommodate more bulky equipment. In addition they are extremely sensitive and will work efficiently over a relatively wide range of temperatures and vibration frequencies.

The two new devices are the Type E Barium Titanate Accelerometer and the Barium Titanate Vibration Strain Gauge.

Type E Barium Titanate Accelerometer

This can detect and measure shocks and vibrations on any object or mechanism over a wide range of operating conditions. It consists of a circular disk of barium titanate of about $\frac{1}{16}$ in thick and $\frac{1}{8}$ in in diameter, which is silvered on both sides and sandwiched between two pieces of brass. One piece forms the base and is terminated by a 2 B.A. stud for fixing purposes. The other acts as an inertia weight which converts the vibrations in the equipment to strains in the ceramic. These strains then generate a piezoelectric charge, proportional to the acceleration applied to the base, which is collected by a coaxial screened cable. The signal is taken to a detector with a suitably high impedance such as a cathode-follower, and can be observed on a cathode-ray oscillograph. The accelerometer is only $\frac{1}{16}$ in long, and can easily be attached by its stud to any piece of equipment whose vibration characteristics are to be studied. It is simply and strongly constructed, yet weighs only 11 grammes, so that the loading effects on the apparatus under test are minimized. The response of the accelerometer to accelerations of up to 1000g is linear and its charge sensitivity of about 5pC/g gives a voltage output of about 20mV/g using conventional circuits. The accelerometer will detect and record frequencies in the range 20c/s to 20kc/s, and between 40c/s and 10kc/s it is accurate to within ± 10 per cent. The transverse sensitivity of the device is less than 5 per cent of the axial sensitivity, so that the direction of vibration can readily be determined by the position in which the unit is mounted.

The accelerometer is effective at any temperature between -50°C and $+100^\circ\text{C}$; if this temperature is exceeded the piezoelectric properties can be restored by repolarization. The voltage sensitivity varies with temperature to the extent of only 0.15 per cent/ $^\circ\text{C}$.

The Vibration Strain Gauge

This was originally developed for measurements of blade vibrations on rotating turbine wheels, but it has many other applications to similar problems. It is two or three thousand times as sensitive to alternating strain as a typical wire resistance strain gauge, but does not respond to steady strain.

The gauge consists of a thin bar of polarized barium titanate with silver electrodes on the two major faces. The electrode on the lower face is extended round one edge on to a small part of the upper face and the leads are soldered on to the two electrodes on the upper face. The under side of the gauge

is attached to the object to be tested by a suitable cement. When the object vibrates, the alternating strains in the plane of the gauge produce an alternating charge on the electrodes, which is fed to a suitable high impedance detector. Unlike the accelerometers, the strain gauges are not supplied calibrated, because they are intended primarily for the deter-



A comparison between two methods of vibration measurement on a turbine blade. In the foreground is a new G.E.C. Barium Titanate Vibration Strain Gauge and behind it the much bulkier equipment for the electro-dynamic measurement of vibration.

The inset photograph illustrates the extremely small size of the barium titanate vibration strain gauge.

mination of the various frequencies at which resonant vibrations occur in mechanical structures, and also of the approximate relative strengths of such vibrations. They will operate in the frequency 20c/s to 50kc/s.

An important feature of the barium titanate strain gauges, not possessed by other types of gauge, is that they can be used either to detect vibrations or to excite them by the reverse process of applying an alternating voltage to the crystal.

The strain gauges are made in two standard sizes, measuring $\frac{1}{16}$ in by 0.035 in and $\frac{1}{16}$ in by 0.035 in, either of which can be used for detection or excitation. The sensitivity is of the order of 0.1V output for an alternating displacement of 1 part in 10^6 .

Reduction of the Minimum Striking Voltage of Hydrogen Thyratrons

A. E. Barrington*, Ph.D., B.Sc., A.M.I.E.E.

Hard-valve pulse-generators are not suitable where a continuously variable output voltage is required. Greater flexibility is obtained with line-type modulators, but their operating range is somewhat restricted because of a threshold voltage below which the hydrogen thyatron switch does not fire. An auxiliary tripping circuit is described, by means of which a conventional line-type pulse-generator is modified to deliver a continuously variable output from 0 to 20kV.

IT is difficult to design a hard-valve modulator where a continuously variable output is required, i.e. for the ageing and testing of pulsed magnetrons. This is due to the grid-current characteristic of pulse-triodes and tetrodes operated with constant grid drive. Typical performance curves¹ are shown in Figs. 1(a) and 1(b), from which it is seen that for low anode voltages the grid current is likely to overheat the grid structure with a corresponding reduction of valve life. It is possible to overcome this difficulty by means of variable grid drive to reduce the grid-current with small load currents. For the particular requirement under consideration (0.2μsec, 0 to 20kV, 0 to 20A), a line type modulator, using the CV2110 (BT83) hydrogen thyatron with a 5:1 step-up transformer, was considered a more convenient design. It was found, however, that the line had to be charged to at least 2kV before the thyatron could be triggered, resulting in a minimum output pulse of 5kV. Since this voltage was too high for the initial ageing of millimetre magnetrons, the auxiliary tripping circuit described in the following section was designed to obtain a continuously variable output from 0 to 20kV.

Operation of Pulse Generator

A circuit diagram of the pulse-generator is shown in Fig. 2, consisting of the auxiliary tripping circuit (circuit 1) and the 0.2μsec pulse-shaping circuit (circuit 2). Thyatron V₂ is triggered from a variable frequency multivibrator (250V trigger pulse), and a 4kV—0.5μsec pulse appears across its 1kΩ cathode load. This pulse is applied to the anode of thyatron V₄ through coupling capacitor C₁ and charging diode V₃, in addition to the continuously variable charging voltage of line 2. Simultaneously, the grid of thyatron V₄ is triggered from cathode resistor R₄. By choosing a suitable value of C₁, energy transfer from line

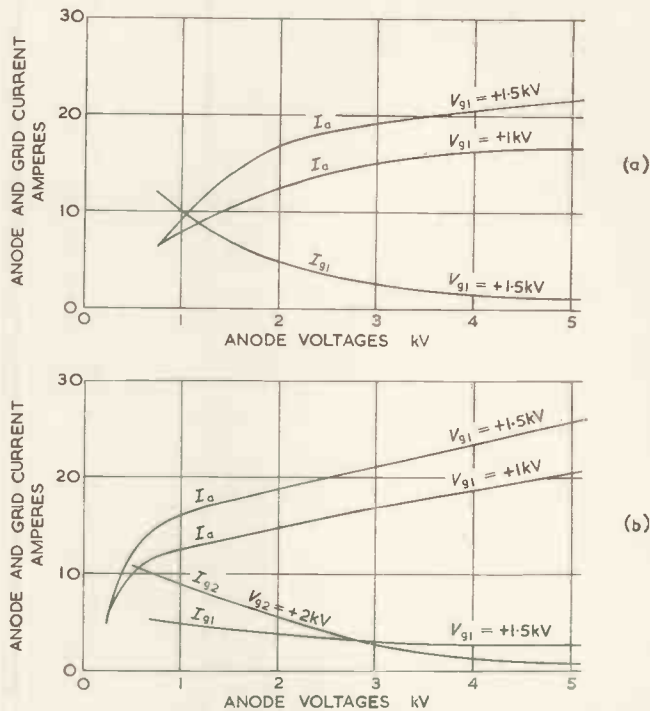


Fig. 1(a). 6C21 triode pulse characteristics
 (b). 6D21 tetrode pulse characteristics

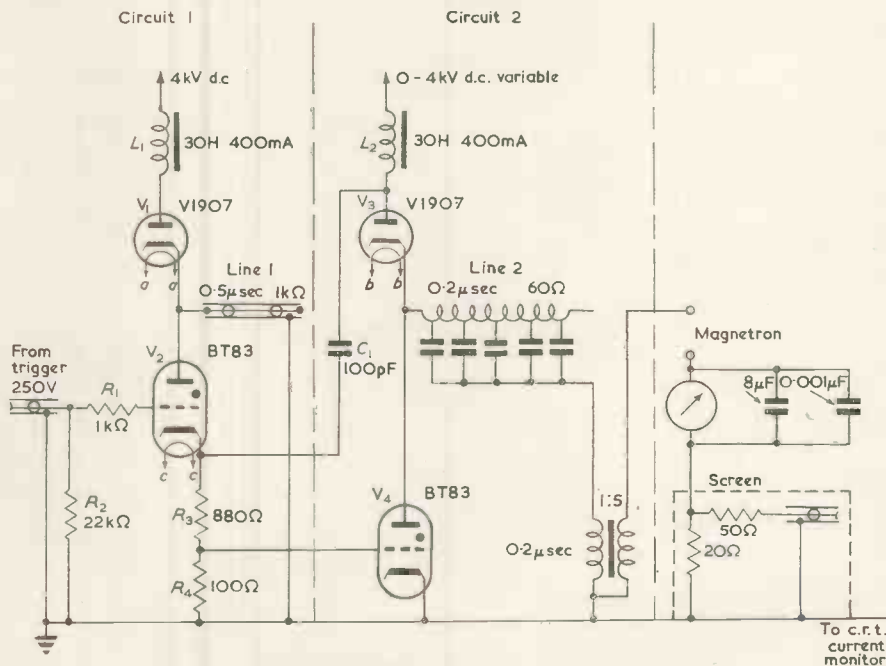


Fig. 2. Variable output test modulator

1 to the pulse transformer is reduced sufficiently to minimize distortion of the 0.2μsec output pulse.

Conclusions

The pulse generator has been in use for over two years. The effect of auxiliary tripping on thyatron life appears to be negligible.

Acknowledgments

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* Services Electronics Research Laboratory Extension, Admiralty, Harlow, Essex

Short News Items

The 23rd Annual Report of the Radio and Electronic Component Manufacturers' Federation mentions that five million radio and electronic components are made by British manufacturers every working day of the week. Production in 1955 rose by 30 per cent compared with the previous year; it has doubled during the past four years and is now at seven to eight times the pre-war level. In value, current output at £58m is stated to be ten times the pre-war level. The United States is now the principal British market for sound reproduction products and Canada the second largest purchaser of components, India being the principal customer.

The International Congress on Automation, organized by the Department of Mechanics of the Conservatoire National des Arts et Metiers, Ministry of Public Education, with the assistance of several scientific and engineering associations and the Association Française pour l'Accroissement de la Productivité, will take place from 18 to 24 June at the Conservatoire National des Arts et Metiers, 292 rue Saint-Martin, Paris. The aims of the Congress are to show the various aspects of "general automation" and its conditions of application (scientific, technical, economical and psychological). Further details of the programme and registration forms may be obtained from J. Auricoste, Secretary of the Organizational Committee, 292 rue Saint-Martin, Paris 3e.

The Atomic Energy Research Establishment at Harwell was founded in 1946 and, to mark the passing of the first ten years, a series of "Open Days" is to be held in the week ending 2 June. On the first four days of this week Members of both Houses of Parliament, correspondents of the British, Commonwealth and Foreign Press and representatives of the neighbourhood will be invited to tour the establishment. On Friday, 1 June, there will be a "University Open Day", when scientists and technologists from universities and Government research establishments and representatives of industry will be invited.

Model of a Philips synchro-cyclotron at the Science Museum. Among the exhibits in the public exhibition held in connexion with the Geneva Conference on Atomic Energy last August was a model of the cyclotron made by N.V. Philips Gloeilampenfabrieken of Eindhoven, Holland, which was taken into use at Amsterdam University in Novem-

ber 1949. By courtesy of Philips Electrical Ltd, London, the model is now being shown for a few months at the Science Museum, South Kensington.

Decca Radar announce that in the six years since they entered the field of marine radar, their equipment has now been ordered for over 5 000 ships of all classes throughout the world. The radar for the 5 000th ship to be fitted was ordered by Furness, Withy & Co Ltd. A reception was recently held at the Savoy Hotel to mark the occasion. Decca Radar has been ordered for one-fifth of the total world registered tonnage; over twenty million gross tons.

A Summer School in programme design for automatic digital computing machines will be held in the University Mathematical Laboratory at Cambridge during the period 17-28 September, 1956. It will be along the same lines as those held previously. A detailed syllabus and form of application for admission may be obtained from G. F. Hickson, Secretary of the Board of Extra-Mural Studies, Stuart House, Cambridge, to whom the completed application form should be returned not later than 15 June.

Marconi Marine radio equipment in the new 26 000 ton Canadian Pacific liner *Empress of Britain* will give her communication facilities unsurpassed in a ship of her class. The installation, designed to meet all requirements for transmission and reception on the marine medium, intermediate and h.f. telegraphy bands, also provides for intermediate and h.f. telephony operation for passengers' messages and ship's traffic.

The Spanish Cibernetic Association are proposing to arrange a congress on Automatic Calculation Techniques. Further information may be obtained from the Sociedad Espanola de Cibernetica, Calle Conde de Penalver 19, Madrid.

Marconi Instruments Ltd announce the signing of contracts with the Canadian Department of Defence for the supply of telecommunication measurement equipment to the value of \$200 000. The orders comprise quantities of signal generators, frequency meters, wattmeters and universal bridges.

The British Thomson-Houston Co Ltd have undertaken a new £8m project at Larne in Northern Ireland which will ultimately provide employment for upwards of 3 000 people engaged on the complete cycle of production of heavy turbine plant. The company, in association with the Faculty of Applied Science and Technology, Queen's University, Belfast, have introduced an Industrial Scholarship plan for boys who are normally resident in Northern Ireland, covering both academic and practical training, in electrical and mechanical engineering.

Decca Radar (Canada) Ltd of Toronto have received an order from the Department of Transport for four Decca MR-75 medium range Airport Surveillance Radars. These sets, the first of their kind in Canada, are to be installed at Toronto, Montreal, Winnipeg and Vancouver airports, where they will be used by the Department of Transport as an aid in the control of air traffic.

The Television Society's Silver Medal instituted in 1948 for rewarding outstanding artistic achievement in television has this year been presented to Mr. Peter Scott, C.B.E., D.S.C. The award was presented at the Society's annual dinner by the President, Sir Vincent de Ferranti.

The Royal Society has recently issued a list of Fellows elected for 1956. Among these are Dr. D. Gabor, Mullard Reader in Electronics, Imperial College of Science and Technology, London, and Dr. A. B. Pippard, Lecturer in Physics, University of Cambridge.

Siemens Bros & Co Ltd announce the formation of a Telecommunication Transmission Division. Operating as a self-contained unit, the division has absorbed the function of the previously existing Carrier Department and will be responsible for all aspects of development, manufacture, sale and installation of equipments.

Pye Ltd, as a result of the Leipzig Fair in February, have received an order for £30 000 worth of television transmission equipment for East Germany. Two-thirds of this equipment, which is for studio broadcasting purposes, has already

been delivered, and the remainder will be despatched shortly. Pye Ltd have decided to exhibit at the scientific exhibition at Ljubljana in Yugoslavia, which is being held from 4-12 August.

Costain-John Brown Ltd, of 73, South Audley Street, London, W.1, have recently issued a set of Cosine and Sine Cursors, together with operating instructions, based on an I.E.E. paper, "An Approximate Method for Obtaining Transient Response from Frequency Response" by Dr. H. H. Ronsenbrock. These cursors are now available from Costain-John Brown Ltd and further particulars may be obtained from them.

The Junior Institution of Engineers announce that, with the aid of funds provided by the trustees of the Maudslay Scholarship Foundation and administered jointly by the Junior Institution of Engineers and the Maudslay Society, scholarships and prizes are offered to young engineers for the purpose of assisting them in their technical education and practical training. Further details can be obtained from the Secretary, The Junior Institution of Engineers, Pepys House, 14 Rochester Row, Westminster, S.W.1.

Ultra Electric Ltd announce that an \$800 000 initial contract for the supply of the search, rescue and homing equipment (SARAH) has been placed with them by the Royal Canadian Air Force. SARAH is already in full production for and installed in aircraft of operational squadrons of the Royal Air Force and, though its use by the R.C.A.F. will be primarily military, it will also serve for civil rescue duty.

Redifon radio equipment has been ordered for the Iraq Government oil refinery at Daura, near Baghdad. Involved in the order are two Redifon G.40 transmitters, R.50m receivers, aerials and ancillary equipment.

Communication Systems Ltd have received an order to supply eleven Wallasey Corporation ambulances with v.h.f. radio telephones, and a base transmitter. Vehicles taking patients to hospitals in Liverpool and other areas some distance from headquarters, will no longer have to return to base to receive further instructions.

A. C. Cossor Ltd announce that orders for their Airfield Control Radar Mk. VI equipment now exceed £1m. Five are operational, including three overseas fittings—the Zurich installation, and two military versions for the Royal Netherlands Air Force—and twelve are still in process of manufacture for customers including the Ministry of Transport and Civil Aviation and the Ministry of Supply.

Dr. Robert Pohl, D.Eng., D.Sc., M.I.E.E., whose death was recently announced, came to England in 1904 and made his name as one of the originators of the interpole, which is now an essential component of practically all electric direct current motors. After nearly twenty years as director and chief engineer of the A.E.G. Turbine Works in Berlin, he became a member of the Electrical Engineering Department of Birmingham University and acted as a consultant to Professor Oliphant on atomic energy machinery. He was also a consultant to the British Thomson-Houston Co and, until his retirement three years ago, a moderator in the University of London.

Mr. N. C. Robertson, C.M.G., M.B.E., deputy managing director of E. K. Cole Ltd and a director of Ekco Electronics Ltd, died a few weeks ago.

The combined Manchester depot of Aerialite Ltd and Nettle Accessories Ltd has been moved to larger premises at 355 Deansgate, Knott Mill, Manchester 3.

20th Century Electronics Ltd announce that Mr. W. R. Daniels has recently joined their senior technical staff as production engineer. Mr. Daniels was previously with the Pye organization.

Lithgow Electronics Ltd have been appointed exclusive British representatives of the Hewlett-Packard Co of California, U.S.A.

Mr. C. H. T. Johnson, commercial director of Decca Radar Ltd, has been elected chairman of the Radio Communication and Electronic Engineering Association for the present year, in succession to Mr. S. J. Preston, a director of E.M.I. Electronics Ltd, who becomes vice-chairman. Mr. Johnson joined Decca in 1946 to assist in the commercial development of the Decca Navigator System. Since the formation of Decca Radar Ltd in 1950, he has been actively concerned with the establishment of the company's overseas connexions, which now cover 44 countries with associated subsidiary companies and agents.

The General Electric, Schenectady, N.Y., announce the opening of a new European office at Pelikanstrasse 37, Zurich 1, Switzerland.

Mr. Sydney H. Brewell, M.B.E., whose election is announced as chairman of the Radio and Electronic Component Manufacturers' Federation in succession to Mr. C. M. Benham, is chairman and managing director of A. H. Hunt (Capacitors) Ltd, of Wandsworth, Wrexham, and New Addington.

E.M.I. Electronics Ltd will, in future, act as sole selling agents at home and overseas for the quantity produced instruments of Industrial Electronics, Magnet Works, Derby Road, East Sheen, London, S.W.14. These instruments, notably the Model 2300 Oscilloscope and the Model 1950/2 a.f. Panoramic Analyser, will be integrated with the E.M.I. Electronics' range of instrument products.

The Plessey Co Ltd announce the formation of an associate company, Plessey Nucleonics Ltd, to handle their increasing activities in the atomic field. This new company will be largely concerned with specialized instrumentation and the supply of raw materials, and electronic, mechanical and hydraulic apparatus associated with nuclear energy projects. It will be particularly interested in the development and production of all forms of control equipment and systems. Directors of Plessey Nucleonics Ltd are Mr. A. G. Clark, who is Chairman and Managing Director, Mr. E. J. Earnshaw, Mr. M. W. Clark and Dr. G. C. Gaut.

The London Electric Wire Co and its Associates, Frederick Smith & Co, The Liverpool Electric Cable Co Ltd, Vactite Wire Co Ltd, announce the opening of new and larger London Branch premises carrying increased stocks of bare and insulated wires and cables at Lewcos House, 57/61 Regency Street, London, S.W.1. Telephone Tate Gallery 8611.

H. O. Serck Ltd, manufacturers of radiators for motor cars, aeroplanes, tractors and stationary engines, have recently installed Pye v.h.f. radio telephones in all their service vehicles operating from the main works in Manchester. Cases arise daily where work has been collected within minutes of receiving a telephone call to collect from a customer, thus saving valuable time to the vehicle user.

Tufnol Ltd announce the opening of a new branch office at Exchange Buildings, Quayside, Newcastle-on-Tyne, 1. Telephone Newcastle 29693. From this office will be conducted the sales and technical service for Tufnol in the North-Eastern area of England.

Errata. It is regretted that there are two misprints in the article "Improved Permanent Magnet Materials", which appeared on p. 171 of the April issue. In the second line of the penultimate paragraph for 'BH' read 'B/H'. In the fifth line of the same paragraph for 'decreased' read 'increased'.

LETTERS TO THE EDITOR

(We do not hold ourselves responsible for the opinions of our correspondents)

The Electron Gun of the Cathode-ray Tube

DEAR SIR,—In his discussion of the relative merits of triode and tetrode television tubes (December 1955 issue) Dr. Darbyshire makes a number of erroneous statements. In particular, he refers to a "fundamental" difference between triodes and tetrodes. Fundamental considerations lead one to the conclusion that there should be little to choose between the electron optical properties of triodes and tetrodes, and this conclusion is confirmed by experiment.

If, following Dr. Darbyshire, we consider the equivalent optical analogy—which at best only approximately simulates the electron lenses concerned—we find that he omits the post-crossover lens L_2 in the case of the triodes. There is no justification for this as it is the lens L_2 which produces the virtual crossover described in the discussion of the triode. This lens will always exist in both triode and tetrodes due to the accelerating field produced by the final anode. The power of the lens, however, may vary widely from one design to another in both triodes and tetrodes. Quite powerful lenses of this nature have been used in commercial triodes for many years and consequently such tubes are plug-in replacements for a number of tetrodes as shown in Table 1.

The fact that L_2 can be very powerful in a triode is demonstrated in the 21in 90° scan angle tube. For 90° scanning very small beam angles are required, and the value given in the table has been chosen as giving excellent focus uniformity with standard permanent focus magnets and deflector coils. Still smaller beam angles can be obtained but no further advantage is gained by doing this. The power of the modulator-final anode lens is controlled by the application of normal electron optical principles and does not involve unusual clearances or tolerances anywhere in the gun.

Control of beam angle is largely achieved by cupping the electrode nearest to the final anode in all television tubes. In fact, the dimensions used are often so similar that the first anode from a tetrode could be used as the modulator of a triode to produce a tube of very similar performance. To sum up, much of the article is based on an incorrect assumption and consequently the wrong conclusions are drawn. It is said to compare the triode with the tetrode, whereas in fact it compares wide and narrow beam angle guns which in either case may be triodes or tetrodes. We conclude that the only necessary difference between the two types is that the cut-off voltage in a tetrode is dependent on the first anode potential and not that of the

final anode. Dr. Darbyshire rightly points out that this difference is not so significant as it might appear, and also that the commonly used analogy with the valve (higher slope in the tetrode etc.) is not valid.

TABLE 1
Beam angles for some modern television tubes

	BEAM ANGLE AT 100 μ A (Degrees)
Triode 14in. 70° ..	1.9
Tetrode 14in. 70° (manufacturer A)	2.1
Tetrode 17in. 70° (manufacturer B)	1.9
Triode 21in. 90° ..	1.3

The tests were carried out with the tubes arranged to cut-off at about -60V.

Yours faithfully,

R. C. HART

Research Laboratories
The General Electric Co. Ltd.,
Wembley, Middx.

The author replies :

DEAR SIR,—Mr. R. C. Hart criticizes the expression "fundamental difference between triode and tetrode".

The triode differs from the tetrode in the following respects:—

- (1) There is an extra electrode in the tetrode.
- (2) An additional electrical supply is required for the tetrode.
- (3) The basing of the tube is different.
- (4) The relationship between the final anode voltage and modulator cut-off is completely different.

In view of these differences I think that criticism of the word "fundamental" is somewhat unnecessary.

Mr. Hart then points out that it would be desirable to indicate the presence of a lens (similar to L_2 in the tetrode) just after the crossover in the diagram of the optical system of the triode.

The existence of this lens is usually understood and if it is to be inserted in the triode another similar lens should also (in principle) be inserted in the diagram of the tetrode.

In the remainder of his criticism Mr. Hart rather fails to appreciate that the article has been written to cover triode and tetrode guns in general and not with specific reference to those guns designed for use in television cathode-ray tubes. I consider that I was justified in adopting the point of view that there is a "conventional triode" and also a "conventional tetrode". Also that the conventional triode is essentially a type of gun which has a wider beam angle of

convergence to the spot on the screen (Θ_s) and a lower magnification ratio than the conventional tetrode. Also, it must be remembered that for certain types of cathode-ray tubes the wider beam angle Θ_s and lower magnification ratio of the triode is desirable. Again, for other types of cathode-ray tubes the triode should be designed to have a rather narrow beam angle, Θ_s , but still with a low magnification ratio. The conventional tetrode is essentially a tube with a narrow beam angle, Θ_s , and high magnification ratio.

In the light of these terms of reference I cannot see that I have made any false assumptions nor arrived at any erroneous conclusions. The assumption that I should have made apparently is that all triode guns have been designed by Mr. Hart—that they all have tetrode characteristics—and therefore that there is nothing to write about at all.

I would agree with Mr. Hart that I should have included in the article a discussion of those triodes which have been designed with a powerful lens action between anode and modulator such that their electron optical performance is very closely allied to that of the tetrode and I hope that the article does not give the impression that guns of this type are to be considered as unsatisfactory. Nevertheless, I must still state categorically that I would prefer to use the tetrode when the "conventional" tetrode performance is required rather than to "tetrode the triode", a procedure which is evidently strongly sponsored by Mr. Hart.

Yours faithfully,

J. A. DERBYSHIRE

Chief Physicist,
Ferranti Ltd.,
Manchester.

DEAR SIR,—I have read with interest Dr. Darbyshire's recent article on the merits of triode and tetrode cathode-ray tubes and Dr. Darbyshire has kindly allowed me to read Mr. Hart's reply. I have had the privilege of association with both these gentlemen and may perhaps be allowed to intervene in the dispute.

This subject is a classic cause for heat around the collars of c.r.t. engineers and the introduction of a pentode by one leading manufacturer has given the whole matter a fascinating twist.

I feel bound to agree with Mr. Hart in that Dr. Darbyshire's article becomes largely a discussion of wide and narrow-divergence electron guns and that these have been explicitly associated with triodes and tetrodes respectively. This fallacy may have arisen from a comparison between triodes of antique English design and tetrodes which follow current American practice. It is possible and

quite practical to design triodes having the performance of tetrodes (even the pentode can be dealt with in this fashion) provided that the running conditions are completely known, as a degree of freedom is lost. The c.r.t. which results may be slightly cheaper to manufacture and is generally less prone to astigmatism. It is interesting to note that conventional oscilloscope tubes are really triodes since there is no electrode between the first anode and the focusing cylinder.

Uncertainty about the conditions of use (e.g. variation of e.h.t. voltage) undoubtedly favour the tetrode for television or radar applications and the manufacturer finds it convenient to use one basic design for many purposes, where otherwise a number of different triodes would have to be produced. The sale of tetrodes has been further aided by an appeal to U.S. standard practice and to an erroneous comparison with the tetrode valve. It must also be remembered that most of the triodes in circulation in this country, and some indeed of current manufacture, are based on pre-war designs.

The tetrode fashion has been set and must be allowed to run to seed before improved triodes receive acceptance in the rôles for which triodes are most suited. Until then, manufacturers are wise to stick to tetrodes.

A copy of this letter has been sent to Dr. Darbyshire.

Yours faithfully,

M. D. DUDLEY
C.R.T. Laboratory,
Ferranti Ltd.

High Impedance Current Generators

DEAR SIR,—After seeing the article in your December 1955 issue by Mr. J. H. McGuire on "Some High Impedance Current Generating Circuits" I wonder whether Mr. McGuire and also perhaps some of your readers may be interested in a somewhat different approach to the problem.

The basic circuit is shown in Fig. 1, where E is a voltage having the waveform required of the current I flowing in the variable impedance Z .

The error in the voltage IR relative to E is detected and amplified by the valves V_3 and V_4 and applied to the correcting valve V_2 .

It can be shown that the current I is given, accurately enough for practical use, by the expression.

$$I = \frac{-EA\mu_2}{R\mu_2(A+1)+Z}$$

where μ_2 is the amplification factor of V_2 and A is the gain of difference amplifier $V_3 + V_4$.

For example, suppose

$$\begin{aligned} E &= 160V \\ A &= 50 \\ \mu_2 &= 20 \\ R &= 40k\Omega \end{aligned}$$

$$\text{then } I \approx \frac{-160 \times 10^3}{40 \times 10^6 + Z} \approx 4mA$$

In other words the circuit behaves as though the source had an e.m.f. of 160kV and an internal resistance of 40M Ω .

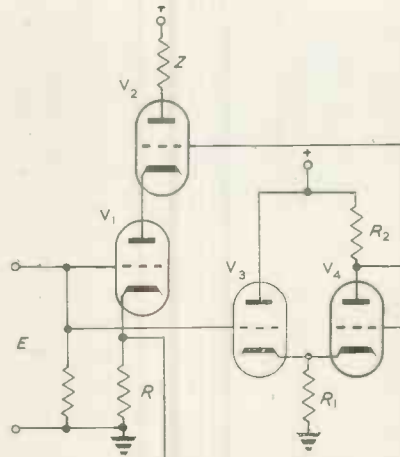


Fig. 1. Basic circuit of current generator

As a verification of the theory the circuit of Fig. 1 was tested with the following values

$$\begin{aligned} V_1 + V_2 &= 6SN7, & V_3 + V_4 &= 6SL7, \\ E &= 160V, & R &= 40k\Omega, & R_1 &= 50k\Omega, \\ R_2 &= 500\Omega, & \text{H.T. supply} &= 500V \text{ d.c.} \end{aligned}$$

The constants are comparable with those assumed in the example above.

As measured by a potentiometer the current falls by about 3 μ A in 4mA as the value of Z is increased from 0 to 50k Ω , i.e. as the voltage drop across Z increased from 0 to 200. The change in current is thus less than 0.1 per cent and the apparent internal resistance is somewhat greater than 50M Ω . Although a d.c. generator is used as an example (for ease of current measurement) the basic circuit is equally suitable for a.c.

It is hoped to publish a fuller account of this type of circuit in the near future.

Yours faithfully,

L. N. CLARKE,

Division of Forest Products,
Commonwealth Scientific and
Industrial Research Organization,
Melbourne.

The author replies :

DEAR SIR,—Mr. L. N. Clarke's Circuit appears to be most valuable where the load may be inserted in the h.t. line and where very high output impedance is required. The inclusion of extra stages of gain, without the necessity of raiding the h.t., is an important attribute of his circuit.

Yours faithfully,

J. H. MCGUIRE
Department of Scientific and
Industrial Research.

PUBLICATIONS RECEIVED

PRINCIPLES OF RADIO is the subject of a set of three wall charts showing in clear diagrammatic form the basic principles of electronics and of radio. The first chart deals with amplification showing the movement of electrons and the operation of the valve as an amplifier. This is followed by charts on reception, the valve as a detector and oscillator, and the principles of a typical superhet receiver. These charts have been published in collaboration with the E.M.I. Institute and are available to schools in this country at the nominal cost of 3s. EP Educational Productions Ltd, East Ardsley, Wakefield, Yorkshire.

CONTACT MATERIALS—PROPERTIES AND AVAILABILITY, CONTACTORS—CHOICE OF CONTACT MATERIALS and SILVERED MICA CAPACITOR PLATES are the subjects of the first three of a new series of technical data sheets dealing with the products and services for the electrical and allied industries produced by Johnson, Matthey & Co Ltd, 73-83 Hatton Garden, London, E.C.1. These sheets, which are to be issued at the rate of two per month during the next two or three years, will together form Publication 1300, "Electrical Engineering Data".

CONTROL GEAR CATALOGUE giving details of control gear available for the first time to British industry has been issued by Square D Ltd, the recently formed British subsidiary of America's switchgear manufacturers, the Square D Company. All the items shown are now in production and are immediately available. Copies of the catalogue are available from Square D Ltd, 100 Aldersgate Street, London, E.C.1.

PHENOLIC MOULDINGS is No. 4 of a series of reports covering tropical trials on plastics which have been arranged by the Ministry of Supply/British Plastics Federation Joint Sub-Committee. Her Majesty's Stationery Office, Kingsway, London, W.C.2. Price 4s.

FACTORY AND WORKSHOP PROCESS HEATING APPLIANCES is the title of a new catalogue describing a range of the smaller and portable industrial heating equipment manufactured by Barlow-Whitney Ltd, Coombe Road, Neasden, London, N.W.10. This equipment has wide applications in many industries ranging from radio to rubber, from plastics to printing, and from aircraft to artificial silk.

THE SINGAPORE TELEPHONE BOARD have issued an Interim Report and Development Plan. Malaya House, 75 Trafalgar Square, London, W.C.2.

POLAR VARIABLE CONDENSERS, TRIMMERS AND DRIVES is a catalogue giving details of equipment produced by Wingrove and Rogers Ltd, Domville Road, Mill Lane, Liverpool, 13.

LABOUR ACCOUNTING is the first publication which attempts to explain in full how the use of electronic accounting can provide managements with vital statistics relating to labour efficiency and costing in advance of the production of final payroll figures. This information has for long been desired but it is only now, with electronic methods, that it has been made easily and rapidly accessible. The brochure describes how the statistics are obtained as a simple by-product of payroll compilation. Using punched cards and the new Hollerith Type 550 Electronic Calculator, the procedure assembles the payroll at high speed. The British Tabulating Machine Co. Ltd., 17 Park Lane, London, W.1.

NEOPRENE NOTEBOOK is the title of a new monthly technical and industrial bulletin on Neoprene Synthetic Rubber. Those who would like to receive regular copies of the Notebook should communicate with Durham Raw Materials Ltd, 1-4 Great Tower Street, London, E.C.3, the U.K. distributors of Neoprene.

ELECTRONIC EQUIPMENT

A description, compiled from information supplied by the manufacturers, of new components, accessories and test instruments.

V.L.F. Output Transformer

(Illustrated below)

AMONG the new components shown on the Haddon exhibit at the recent R.E.C.M.F. Exhibition was a very low frequency output transformer.

This unit is capable of delivering 1kW of power continuously in the frequency band 6c/s to 2200c/s and on reduced power the frequency band is considerably extended. The transformer has been especially designed and developed for driving vibration generators which over the past few years have become used extensively in the vibration testing of metals, assemblies, etc., both in the electronic and aircraft industries.



It is designed to operate from an 8k Ω source in class-B push-pull and the secondary windings are so arranged to give output impedances of 2.5 Ω , 10 Ω and 40 Ω . There are variations of this unit with other secondary impedances to match almost any requirement.

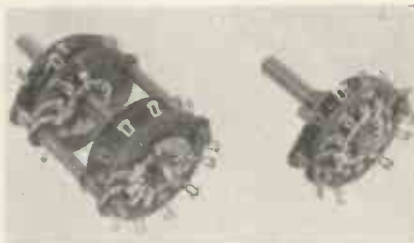
The primary open-circuit inductance varies between 850H to 2000H depending on the voltage applied. The leakage inductance primary to secondaries is 100mH, the dynamic shunt capacitance (referred to primary) is 2200pF and the efficiency is of the order of 89 per cent. The overall size 20 $\frac{1}{2}$ by 18 $\frac{1}{2}$ by 17in high and the weight is 4/5 cwt.

Haddon Transformers Ltd,
Masons Avenue,
Wealdstone,
Middlesex.

Rotary Switches

(Illustrated above right)

THE Plessey G.A.1 is a compact rotary wafer-type switch and it can be constructed either as a single-wafer or multi-wafer unit with up to 12 positions. Each wafer permits up to 20 fully-insulated fixed contacts to be fitted. The contacts, which are of the double-wiping type are fixed to the stator board by a new method which ensures that the tags



remain immobile under tangential pressure.

Outstanding features of the new switch include the use of "Wedglock" rivets which provide adequate lateral support and unusual tag strength. These rivets allow the whole design of the switch to be revised and the tags can be mounted on the surface of the wafer instead of being supported by cut-away sections. A much stronger wafer results and tags of the best possible shape can be used, thus providing more consistent contact with an effective self-cleaning action. In addition, the surface mounting of the tags permits the conventional rotor to be replaced by a strong rigid assembly with improved insulation resistance. These tags are mounted at an angle which enables separate sets of contacts to be placed on either side of the wafer without additional insulating members which weaken the structure and introduce additional electrical losses.

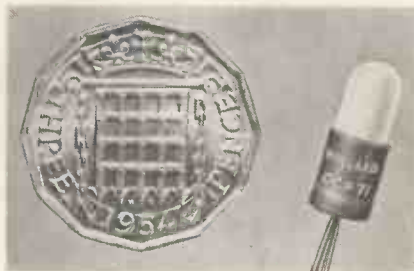
The Plessey Co. Ltd,
Ilford,
Essex.

Germanium Phototransistor

(Illustrated below)

THE phototransistor, type OCP71, is similar in form to a conventional low-power junction transistor, and costs little more. It is sufficiently sensitive to operate a relay of normal type directly.

In common with other kinds of transistor, the OCP71 has the advantages of small size, and the ability to operate from low voltages. The circuits in which it may be successfully employed are extremely simple—they may amount to nothing more than the phototransistor connected in series with the relay coil and a battery of 12 to 18V. For most



applications the base is left floating so that only two connexions to the phototransistor are required. If it is required to operate the phototransistor over a wide range of temperatures the base electrode can be fed with a small positive compensating bias as a means of maintaining the dark current at a low level.

The dark current at 25°C is not more than 300 μ A; this is quite small compared with the light current which can be of the order of 5 to 10mA. The spectral response is peaked in the infra-red region, but continues into the visible light region.

Mullard Ltd,
Century House,
Shaftesbury Avenue,
London, W.C.2.



V.L.F. Oscillator

(Illustrated above)

THE Dawe Instruments v.l.f. oscillator type 442 covers the frequency range of 0.1c/s to 10kc/s in five decades with a calibration accuracy of ± 3 per cent. An important feature is the provision of two outputs in quadrature (each continuously variable up to 25V into a minimum load of 10k Ω). These quadrature outputs are of considerable value in the testing of servomechanisms.

Essentially the oscillator circuit employs a direct-coupled valve amplifier which is made selective by the use of resistance-capacitance networks and overall negative feedback. The positive feedback circuit, which is necessary to produce self-oscillation, includes a symmetrical diode limiter. The constant-amplitude rectangular waveform produced by the limiter is applied to the input of the amplifier. Due to the high selectivity of the amplifier, the output signal is sinusoidal with a total harmonic distortion of about 0.3 per cent at the 0° output and 1 per cent at the 90°, or quadrature, output. The limiter circuit thus provides a rapid and automatic control of amplitude which is effective down to the lowest frequency. The output signals are monitored by a miniature cathode-ray tube.

Dawe Instruments Ltd,
99, Uxbridge Road,
London, W.5.

Miniature Selenium Rectifiers

A RANGE of miniature selenium rectifiers has been introduced by The General Electric Co. Ltd. In half-wave capacitive and voltage doubler circuits the output rating when operating in 35°C ambient temperature is 4mA at mean output voltages between 16V and 7040V according to the number of series elements and the method of connexion. For resistive load circuits the ratings are 5mA in half-wave connexion and 10mA in bridge connexion at the same ambient temperature.

The rectifiers are made in moulded polythene or resin-bonded paper tube types. All moulded polythene units have the same dimensions (14.5mm tube length by 9.5mm diameter), regardless of the number of series elements, which varies from one to nine according to the voltage. The resin-bonded paper tube units can be supplied with wire, screw or plain cap terminals and contain from ten to 440 elements in lengths between 51mm and 305mm. Tube diameter is 11.25mm

The General Electric Co. Ltd,
Magnet House,
Kingsway,
London, W.C.2.



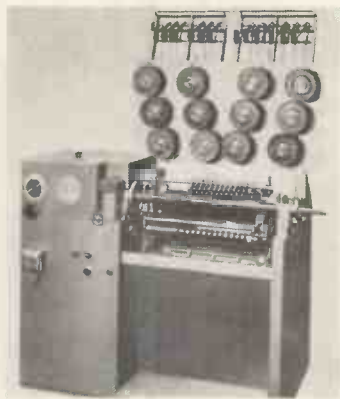
open or closed, or the time between two successive short-circuits or between two consecutive positive-going pulses.

Venner Electronics Ltd,
Kingston By-Pass,
New Malden,
Surrey.

Coil Winder

(Illustrated below)

THE principal feature of this new multi-winder lies in its ability to accommodate 12 reels each of 6in



diameter, with a winding range of from 20 to 46 s.w.g.

The machine has a traverse from 1/16in to 6in with a maximum effective winding length of 18½in, and an automatic cut-out operates in the event of wire breakages. The maximum coil diameter is 4½in and the minimum ½in. When changing from one gauge wire to another, the operator or setter can see the required setting from a small dial.

The coil winder is driven by a 1.25 b.h.p. a.c. motor with electric clutch control ensuring smooth acceleration in speed from 0 to 2500 rev/min. It possesses a predetermined electric revolution counter with a Warner electric brake on a mandrel headstock to ensure accurate control and prevent over-running.

Starting is by means of an "inching" pedal after which push button control becomes effective and the machine runs automatically.

Westool Ltd,
St. Helen's Auckland,
Co. Durham.

Multiple Circuit Switch

(Illustrated below)

THE Crater multiple circuit rotary switch has been designed to enable a wide variety of circuits to be controlled by one basic type of switch. It consists, essentially, of six changeover contacts of the silver button type operated by a carefully timed arrangement of cams. A



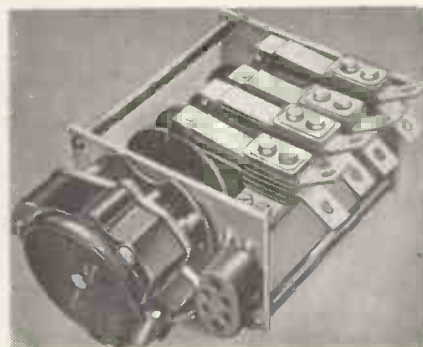
comprehensive booklet has been prepared showing the exact contact arrangements and the method of strapping terminals to give different switching combinations.

Crater Products Ltd,
The Lye,
St. John's,
Woking,
Surrey.

Sequence Timer

(Illustrated below)

THE type HCST timer is driven by a synchronous motor geared to a shaft which carries cams. The cams operate the switch contacts in a sequence, and at time intervals, which are specified by the user. The normal switching capacity is 15A at



240V a.c. By the choice of suitable gearing the total timing cycle can be anything between 1 second and 30 days; the timing accuracy is normally of the order of ½ per cent.

Electrical Remote Control Co Ltd,
Elremco Works,
South Road, Temple Fields,
Harlow New Town,
Essex.



PAC Units

(Illustrated above)

THE PAC unit consists essentially of a complete circuit of resistor and capacitor elements ¼in diameter by ½in long—which may range in number from three or four to over ninety—with all associated connexions embodied in a single fully moulded and protected assembly of small dimensions, and with terminations in the form of special spill-type pins, for insertion into holes or eyelets in the embossed or printed circuit panel for dip soldering.

Erie Resistors Ltd,
Carlisle Road,
The Hyde,
London, N.W.9.

Millisecond Stop Clock

(Illustrated above right)

THE Venner millisecond stop clock is a crystal controlled unit which is capable of measuring time to the nearest 0.1msec. Dekatron cold-cathode tubes are used to indicate the passing of time below 1sec, times greater than a second being indicated on a mechanical counter. The instrument will indicate the duration that a pair of contacts are

BOOK REVIEWS

Machine Translation of Languages

Edited by William N. Locke and A. Donald Booth. 243 pp. Demy 8vo. John Wiley & Sons, Inc., New York, Chapman & Hall, Ltd., London. 1955. Price 48s.

TO suggest that the techniques of the electronic computer might be applied to translation of languages appears, at first sight, to be a presumption on the part of the engineer. The problems are obvious. There are the grammatical differences between languages, such as those of inflected word-endings and of word order in the sentence. There is the difficulty of recognizing the root, or dictionary-listed form, of a word which carries an inflected ending. A selection must be made of the intended meaning of an ambiguous word in the "input" language, and of the most appropriate equivalent, where there are several available, in the "output" language. And, of course, there is the aesthetic question of literary style. It came as a surprise to your reviewer therefore, on reading these 14 essays, to find so many linguists who do not only have faith in the proposal, but who have been carrying out detailed studies over the last few years.

Their research derives its impetus from recognition of the fact that a great deal of scientific published matter is lost to much of the world because there are not enough human translators, whence there is value in a machine that can produce even most elementary translations if therefrom one can form an opinion as to which articles are significant and worthy of further attentions.

The courage to make a start was perhaps born of humility in outlook: a computing machine is worthless unless it be always accurate, but a translating machine can have gross imperfections and yet be of use. Sufficient work has now taken place, however, to show that automatic procedures can be devised which will allow translation of a surprisingly high order to take place. We are by now familiar with the fact that the digital computing machine, often replacing the niceties of mathematics by the most cumbersome procedures, succeeds by virtue of the large capacity of its stores and its extremely high speed of operation. So too the translating machine goes about its problems by a multitude of exploratory steps which it can handle by virtue of large stores and rapidity of working.

There are various approaches. A (human) pre-editor, familiar with the "input" language only, can so amend the input text as to simplify the routines of the machine, for example by eliminating ambiguities. Or a post-editor can deal with the output text. One can have both: the ideal, but at the price of

greater complexity in the machine, is to have neither. These, and many other topics, are discussed in these essays. Much attention is paid to the planning of the machine's store or dictionary so as best to facilitate the recognition of root-words and suffixes and the resolution of ambiguities, and practicable automatic translation procedures are given for one or two languages whose structure is examined in some detail.

This is a book concerned chiefly with language, and certainly not with electronics, but it is one which every electronic engineer should read, for undoubtedly machine translation of languages has now come into his field.

T. L. CRAVEN

The Fundamentals of Electroacoustics

By Dr. F. A. Fischer. 184 pp. 101 figs. Demy 8vo. Interscience Publishers Ltd. 1956. Price 45s.

THERE is now a formidable literature on electroacoustics. Several books are equally authoritative, and since progress in this science is not so rapid as to require a constant succession of new texts, one may come to the conclusion that some of the authors favour expanding a particular aspect of the subject in which they specialize, rather than a general extension of existing knowledge.

This is so in the case of Dr. Fischer's book. He deals very exhaustively with the behaviour of coupled systems at resonance. One is immediately struck with the painstaking and thorough presentation of electro-mechanical vibrating systems, and the analogies which have been devised to cover every combination of mass, compliance and energy storage device. The tenor of the book is completely fundamental and the difficulties of translation are often manifest in the rather long approach to some of the problems.

Chapter I analyses mechanical oscillators, passing by convenient analogies to their electrical counterparts. To this reviewer, the contents of this chapter appear to be better and more thoroughly treated than other sections of the book. Chapter II describes the forces exerted on matter by electric and magnetic fields, and is entirely theoretical. Chapter III deals with the basic laws of electroacoustic energy conversion and includes a good analysis of the piezoelectric transducer.

Chapters IV and V introduce the differential equations of transducers used as sound sources and sound receivers (microphones), although in a rather abridged manner, the theoretical

efficiency of these two devices forms the subject matter of Chapters VIII and IX, and the radiation of sound is presented in Chapter VII. This treatment is very abridged and is largely a condensation from Lord Raleigh's monumental work, "The Theory of Sound". One feels that this material could profitably have been much expanded. A disappointing feature is the dismissal, in two pages, of the conditions necessary for broad-band transducers. Dr. Fischer says in his foreword that this book "grew slowly in the course of years", and this may explain why the basic elements of vibrating systems are so fully covered, but the more modern extensions to the theory are perhaps not quite as fully developed as they might have been.

A bibliography has been supplied by the American translators, which has evidently been selected to include works covering such aspects of electroacoustics as have not been touched on by Dr. Fischer. There is an extensive list of symbols, terms and units which is very necessary. Since the fundamentals of electroacoustics are now so well established, would it not be possible to achieve more uniformity amongst authors in the use of particular symbols for particular purposes?

For those interested in the extreme fundamentals, and especially in the theories of coupled vibrating systems at resonance, this book is sound, accurate and authoritative.

ALAN DOUGLAS

Static and Dynamic Electron Optics

By P. A. Sturrock. 240 pp. 30 figs. Demy 8vo. Cambridge University Press. 1955. Price 30s.

AMONG the many treatises on electron optics this is a book distinguished as well by its originality as by its scope. Every page bears the imprint of the author's characteristics of mathematical fluency and inclination towards general and powerful methods. This approach has enabled him to compress in 240 small-octavo pages not only ordinary "static" electron optics of systems with symmetry axis, as well as with those which have only a single symmetry plane, including the complete theory of their aberrations; but also a very comprehensive theory of particle accelerators, which contains also some previously unpublished material, and brings the reader right into the front of present-day development.

The method favoured by the author is purely deductive. Everything is deduced from variational principles (adaptations of Hamilton's Principle to the problems treated in each chapter) with the variational function (more commonly known as the "Lagrangian") expanded in terms of progressive "perturbation characteristic functions". This, properly applied, is not only a fool-proof but a very short way of obtaining the aberrations of given optical systems, as well as the errors which arise from small modifications of a system, such as ellipticity,

misalignment, etc. It requires of course a knowledge of the calculus of variations, and of some other mathematical techniques, such as matrices. Even the physicist or engineer who is familiar with the mathematics might have some difficulties when first faced with the deductive method, because it means reaching the practical results of electron optics by the descent from the top of a pyramid, through much unfamiliar ground. He may find that it is necessary to read Sturrock's chapters first forward, then backwards, and finally forward again, but in the end he will find that the triple journey has paid well, and has enabled him to approach new problems with better insight and much improved technique.

The first part, 140 pages, is devoted to "static" electron optics. Chapters I, The Variational Equation, and II, Classical Geometrical Electron Optics, contain the physical and mathematical basis. It is particularly praiseworthy that most of Sturrock's formulæ are either relativistic, or can be easily adopted to the relativistic case. His system of units, highly original, has much to recommend it for practical applications. His notations are often unorthodox (a Glossary would have been welcome) but in most cases better than those in common usage.

The next two chapters, III, Instrumental Electron Optics, IV, The Rotationally Symmetrical System, go over much-covered ground, and yet contain much which is new and useful. The author's original work on asymmetries of electron lenses deserves special mention. Chapter V on Systems of Mirror Symmetry, is also largely original work. It is regrettable that the author's work on systems, with curvilinear axis could not find place in this book, as this is a field of electron optics which may have a considerable future.

The second part on dynamic electron optics has only two chapters, VI, Uniform Focusing in Particle Accelerators, and the particularly remarkable last chapter on Periodic Focusing. Here the reader will be acquainted with the most modern devices, such as strong focusing and the Tuck-Teng beam extractor, and also with the most modern doubts, such as the question whether the giant synchrotrons of 15-30 MeV will not become unstable? This is the first treatise on the matrix theory of accelerators in book form, and contains material which now appears for the first time. Some of the presentation (for instance the chapter on the adiabatic invariants) could have been bettered, but one must be grateful for the material becoming available at all, in such comprehensive form.

The book will be indispensable for all original workers in the field of electron optics and particle accelerators, and must be recommended to all who are interested not only in the practical usefulness, but also in the conceptual beauty of this subject.

D. GABOR

The Mathematical Analysis of Electrical and Optical Wave-Motion

By H. Bateman. 160 pp. Demy 8vo. Dover Publications, Inc., New York. 1955. Price \$1.60.

and

Partial Differential Equations of Mathematical Physics

By A. G. Webster. 440 pp. 97 figs. Demy 8vo. Dover Publications, Inc., New York. 1955. Price \$1.98.

IMMEDIATE interest in these two books will be aroused by the fact that they are two of a number of well-known books published in paper covers at very low prices, only about one half of the cost with cloth covers. Both books are reproductions of the original books, but they are very clear and easy to read. Webster's book needs no introduction. Its purpose is to present systematically the various methods of solving partial differential equations and it does so quite successfully, although for reasons which it is difficult to explain it sometimes lacks inspiration. Since its publication in 1927 the method of integration using Fourier's integrals has been enormously developed by operational and other methods, and there have been many developments also in the use of characteristics. It remains, however, one of the best descriptions of the theory of characteristics for physicists and engineers. However, an engineer will find an enormous amount of useful information in this book.

Professor Bateman's book, published originally in 1914, is one which I had not previously seen, and is now very largely out of date. Enormous developments have taken place in the solution of electromagnetic equations for radio and other purposes, and although this book is of interest, in that it collects a number of interesting results obtained before 1914, there are now many other texts far more useful and more systematic in their presentation. Moreover, this book is essentially one for a mathematician, which may be difficult for an electrical engineer to read.

G. J. KYNCH

FBI Register 1956

1110 pp. Royal 8vo. 28th Edition. Kelly's Directories Ltd and Iliffe & Sons Ltd. 1955. Price 42s.

This edition contains a foreword by the President, Sir Graham Hayman, details of the organization, aims and activities of the FBI at home and overseas, French, German and Spanish sections, classified buyers' guide, alphabetical list of member firms, trade associations, brands, trade names and trade marks.

The Register is compiled by the publishers in close collaboration with the Federation and is used by importers, buyers, Trade Commissioners, Chambers of Commerce, Commercial Attaches, Reference Libraries, etc. throughout the world.

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Notes from _____

NORTH AMERICA

New Semiconductor Devices

The General Electric Company have recently announced several new semiconductor devices. Included among these are the following:

GERMANIUM TETRODE TRANSISTOR

This has a frequency cut-off of 50Mc/s at 85°C. and a power gain of 10dB at 30Mc/s at 25°C with a 2Mc/s bandwidth. It is capable of dissipating 50mW at 25°C and has a rise and fall time of 0.02 μ sec.

DOUBLE BASED DIODE

The silicon double based diode is a microsecond switch having a regenerative switching action between its two stable states. The operation of this device depends on the conductivity of a bar terminated in two ohmic contacts being modulated by minority carriers injected from a junction located on the bar between the ohmic contacts. This characteristic permits the device to be operated as the basic element in astable, monostable, or bistable multivibrators, counters, oscillators, phase or amplitude detectors, regenerative pulse amplifiers and sawtooth generators, in addition to its basic operation as an electrically triggered switch.

The double based diode is a three terminal negative resistance device capable of 100mW dissipation at 85°C and a maximum storage temperature of 200°C. It is capable of operation over a temperature range of from -65°C to +160°C. It has a rise and fall time of 1.5 μ sec.

SILICONE TRIODES

Two new silicon triodes are announced. One of these is a high frequency type with a cut-off at 6Mc/s and a 15dB power gain at 2Mc/s. The other, a power type, has a cut-off at 100kc/s and is capable of dissipating 8W at 85°C or 4W at 120°C.

Colour Television Tubes

At the recent convention of the Institute of Radio Engineers the progress in the production of colour cathode-ray tubes was described. Janes, Headrick and Evans of RCA, reported that as a result of manufacturing experience in making thousands of the RCA type colour tubes, and because of the changes made in the construction and processing of the tube nearly perfect colour purity and white uniformity have been achieved. In their paper, "Recent Improvements in the 21AXP22 Colour Kinescope", they explained the changes made which enable them to achieve these results. Colour purity can be regarded as the ability of the tube to produce each of the three colours over the whole face of the tube without exciting any of the other two phosphors. The higher the colour purity the better a tube is able to render a completely black and white picture when no colour is broadcast.

The General Electric Co. has been developing a colour tube of its own. C. G. Lob described the development work that has been accomplished to date. This tube like the RCA tube uses three guns, one for each colour. However, instead of having a shadow mask with the spaced holes through which the electron beams converge, this tube uses a wire grill. The colour phosphors are deposited in stripes on the face of the bulb. The advantage claimed for this design is that the tube gives a much higher bright-

ness level than the shadow mask types and would be cheaper to manufacture but that some of the picture detail and contrast would be lost because of secondary emission at the screen.

CBS-Hytron engineers have sought to overcome the low light output of the shadow mask tubes by the addition of a focusing action between the aperture mask and the phosphor screen. Fyler, Cain and Hambleton described how they acquired the focusing action without the addition of any mesh or grill structure. They reported that mask transmission, efficiency and light output have been greatly improved.

Microwave Transmission Prediction

The Signal Corps Engineering Laboratories have developed a new technique for exploring u.h.f. and microwave transmissions beyond line-of-sight which is expected to result in an increase in the use of these frequencies. Using a standard Army radar set and photographic processes, a map is produced in a few minutes which shows the areas in which communication is possible from any given sight. Maps made at Fort Monmouth show that at ranges of 5 or 10 miles it is often possible to communicate by microwaves over paths obstructed by hills, trees or buildings. Using the radar-photographic technique these paths can be located instantly, eliminating expensive time consuming point by point surveys.

In an address to the Institute of Radio Engineers annual convention, R. E. Lacy and C. E. Sharp of the Signal Corps Engineering Laboratories reported they are now using the technique to expedite radio propagation research needed for the National Defence. The technique may also be used for sight surveys for television, mobile police, fire and taxicab radio services and for radio relay circuits.

Transistor Voltmeters

The Millivac Instrument Corporation have recently introduced two transistor-voltmeters: an a.c. voltmeter measuring from 2 μ V to 1kV over the frequency range of 10c/s to 150kc/s and a d.c. voltmeter capable of measuring from 1 μ V to 1kV, the lowest range being 0-10 μ V f.s.d.

Both of these voltmeters utilize the "hushed" transistor technique, described by Volkers, in which the collector junction voltage is zero or reversed. It is claimed that under these conditions transistors have a noise level some 20dB lower than can be obtained with thermionic valves.

Magnetic Field Strength Measurement

A high precision gaussmeter for rapid measurement of magnetic field strength has been announced by Nuclear Magnetics Corporation of Boston, Mass., a subsidiary of The Perkin-Elmer Corporation.

The instrument utilizes the principles of nuclear magnetic resonance. This technique reduces the difficult problem of measuring magnetic fields to the more precise and easier problem of radio-frequency measurement. Absolute measurements with accuracies as high as ten parts in a million can be obtained by this method.

The instrument can be used in calibrating laboratory magnets and magnetic field measurements. Further, it may be used for plotting magnetic field contours and gradients.

Designated the NUMAR Precision Gaussmeter Model M-2, the unit consists of a radio-frequency oscillator, indicating oscilloscope, power supply and a set of four probes which cover the range from 300 to 18 750 gauss. The oscillator is self-calibrating with built-in 100kc/s and 1Mc/s crystal markers.