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Commentary

INCORPORATED in this issue is the second of the supplements dealing with *Electronics in Industry*. As in the first supplement, which we published last April, we have endeavoured to show how electronics is being used either to increase productivity or to raise the standard of the goods produced, in as broad a field of industry as possible. Needless to say, the applications described are representative only, to be exhaustive would require many volumes. Nevertheless, we hope that this brief account will be of service to those electronic engineers already engaged in industry, and also to those industrialists who have a production problem which could best be solved by electronic means.

* * *

The Annual Report and Statement of Accounts of the BBC for the year ending March 31st, 1952, has just been published* and our first impression, after reading this document, is that it covers very little new ground from the technical point of view since last year's Report was issued.

This is not entirely unexpected for the year under review has been a difficult one. At the end of 1951 the BBC completed its twenty-fifth year of operation as a public corporation and its post-war Charter came to an end at the same time. Hopes of a new Charter embodying many of the proposals put forward by the Beveridge Committee were not fulfilled for Parliament was dissolved and the new Government decided that more time was needed for study of the various recommendations. The granting of a temporary Charter for a period of six months has, in the meantime, enabled the BBC to carry on as before, but the temporary nature of the BBC's existence is largely reflected in its present report.

Conditions have not been made any easier by the Government's limitations on capital expenditure, and many of the technical improvements and expansions which had been planned by the BBC have had to be postponed indefinitely.

It is true that the BBC has now completed the installation of its five high-power television transmitting stations although two of these, Kirk o'Shotts and Wenvoe, are making use of standby low-power transmitters. The five low-power transmitters planned are not likely to be erected for some time to come. But these ten transmitters are only part of the larger overall plan for television in this country. Part of this was the building of a new television centre at White City which would house all the studios and administrative offices, but here again progress has been delayed and only the Scenery Block has been started.

Still no nearer solution is the problem of congestion and interference on the medium and long wavebands and the BBC is unable to report any progress on a position "which has long been unsatisfactory and is steadily deteriorating." A partial remedy lies in the provision of a number of low-power stations for those areas where reception is unsatisfactory, but even so the number of such stations is restricted not only by capital expenditure limitations but by the relatively few wavelengths available for such purpose under the Copenhagen Plan.

However, a plan for the erection of twelve low-power stations to work either on existing BBC wavelengths or on an International Common Wavelength was earlier approved by the Postmaster General and in the year under review eight of these have been brought into operation.

The only long term solution is acknowledged by all concerned to be the development of V.H.F. broadcasting, and plans for a chain of V.H.F. transmitters using frequency modulation were laid before the Government early in 1951. Today, the only evidence that the project has not been completely abandoned, apart from the V.H.F. transmitter at Wrotham, is the inclusion of V.H.F. aerials on the masts of the post-war television transmitters. This is regrettably as far as the development of V.H.F. can be allowed to proceed for the moment, for even if permission were given to the BBC to go ahead, the radio industry is too pre-occupied with the rearmament programme to turn over to the production of suitable V.H.F. receivers. Meanwhile Wrotham is left "to waste its sweetness in the desert air."

It is perhaps unfortunate that the urge for economy has led the BBC to deflect its energies from these pressing problems and to direct them instead to the development of automatic equipment for the saving of skilled manpower. There are a number of dull and often very monotonous tasks in the monitoring of programmes and, therefore, any developments of automatic equipment which will enable the BBC's technical staff to engage in less tedious duties is a laudable project.

In this respect the present report is able to give encouraging news. The 150kW transmitter at Daventry, which radiates the Third Programme, is now almost entirely unattended, being monitored by automatic equipment and there are, in addition, a number of automatic monitors in existence in the BBC network which check the quality of the programmes and take the appropriate action if certain faults occur.

But reviewing the past year's progress as a whole we feel that the BBC with all the limitations imposed upon it cannot be looking forward with confidence to 1953. The coming year is likely to be an important one and the Coronation ceremonies alone are likely to stretch the BBC's resources to the limit. As a return exchange for the very successful Anglo-French television week held this year it has been suggested that the Coronation ceremonies would be relayed to Europe, and we are somewhat dumbfounded to learn that the actual ceremony itself will, by an edict of the Earl Marshal, not be televised. There may be sound reasons for this, but in the absence of any satisfactory explanation we feel that this is an additional handicap on the BBC and one which should be lifted as early as possible.

* *HMSO Cmd.* 8660. *Price* 4*s.* 6*d.*

A V.H.F. Multi-Band Panoramic Receiver

Developed for Spacing and Monitoring Four Home Office Transmitter Networks

By E. W. Crompton *

Home Office County Radio Schemes, provided mainly for the use of the Police and Fire Services, give facilities for two-way communication between headquarters and wireless cars in the various counties. For conveying outgoing messages the multi-carrier amplitude modulation System[1,2] *is used. This system involves the use of several unattended* V.H.F. *transmitters, operating on slightly differing frequencies, and located about 10 to 30 miles apart. The carrier frequencies employed are in the band 90 to 100Mc/s, a "spacing" of 7 and 12kc/s between carriers being satisfactory in a 3-station scheme. The car receiver, with a passband of approximately 50kc/s, accepts all these signals indiscriminately, the heterodyne frequencies being rejected in the* A.F *section. The equipment described is used for spacing the transmitters correctly, and for the simultaneous monitoring of the radiation, modulation, and frequency spacing of four such transmitter networks.*

THE maintenance of all equipment within a large area covering several counties is carried out from a central depot, and quick and accurate fault diagnosis is essential with transmitters often 50 or more road miles away. For this purpose a panoramic receiver offers several advantages: (a) it separates the signals from the several transmitters of a network and clearly indicates their relative amplitudes, provided that limiting is not allowed to occur; (b) by injecting an R.F. signal modulated by a sine-wave of $x$kc/s, the two sidebands $2x$kc/s apart can be made to coincide with any two of the incoming signals to determine the spacing accurately, the limits of accuracy being determined chiefly by the size and spot characteristics of the C.R.T. used for the display. In practice an accuracy of ± 500 cycles is satisfactory, and a 2in. trace is found to be sufficient; (c) under the required operating conditions it has an inherently poor audio H.F. response in its pulse-forming stages, thus circuit and incoming noise has little effect. It is consequently possible to display weaker signals than could be resolved by the equivalent normal receiver; (d) the sides of the displayed pulse indicating any one of the county transmitters are displaced sideways in sympathy with the low-frequency components of the carrier modulation, visually in approximate proportion to the depth of modulation. In practice only an approximate indication of the modulation level is required for monitoring purposes.

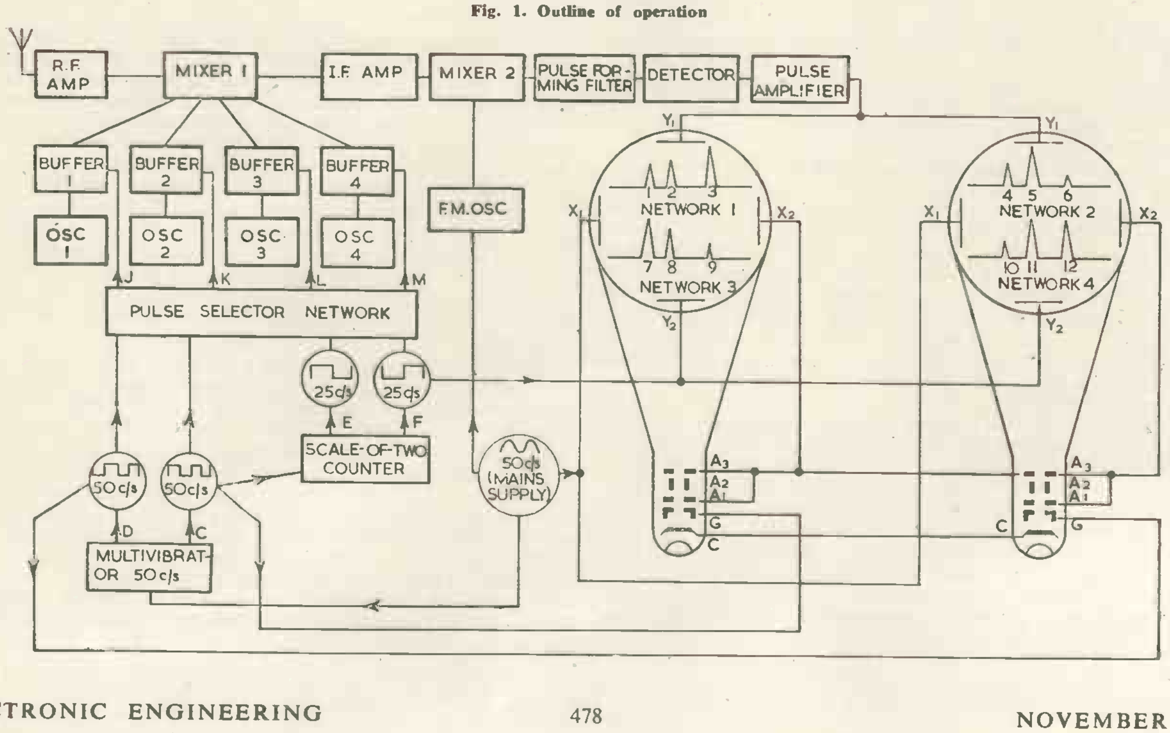
For economy and simplicity it was decided to make one receiver monitor four county schemes simultaneously.

* *Communications Branch, Home Office.*

Outline of the System

An outline of the system used is given in Fig. 1. The four groups of staggered frequencies used for the four county schemes are passed by the wideband amplifier into

Fig. 1. Outline of operation



the first mixer. Oscillator sections 1-4 are each crystal-controlled, and each develops an output frequency 4·5Mc/s lower than the centre frequency of the corresponding scheme, but at any given instant only the output from one oscillator section is injected into the mixer. Assuming that there are three transmitters in each of the four networks, twelve signals may be present at the signal grid of the mixer. When oscillator 1 is operative, only the three signals from network 1 are accepted by the 4·5Mc/s I.F. amplifier, which has a bandwidth of 100kc/s. (The signals from the other county networks are rejected because for normal anti-interference reasons centre frequencies are set at least 500kc/s apart.) The three signals are fed into mixer 2, together with the output of a frequency modulated oscillator operating on a centre frequency of 4 415kc/s, and having a 50c/s sinusoidal sweep adjustable up to ±30kc/s. An 85kc/s filter of 1kc/s bandwidth in the output of mixer 2 responds to each of the three signals in turn, giving, after detection and amplification, three of the response-curve "pulses" typical of panoramic reception. These are presented as Y deflexion on one of four traces, each produced by the application of the same 50c/s sinusoidal waveform to the appropriate X plates of two C.R.T. indicators.

Each network is accepted by the receiver once in every two cycles of 50c/s, i.e., once every 40msec. The positive-going waveform of the first cycle is used to produce indicator-trace 1 and the negative-going waveform to produce trace 2, the second cycle similarly producing traces 3 and 4. The output from the receiver is applied to all the traces, but only one trace is visible at any given instant. When trace 1 is visible, an interlocked electronic switch makes oscillator section 1 operative, so that the three transmitters of network 1 are indicated on this trace. Similarly, the other three networks are made to appear on their individual traces, so that when the four networks are operative the four groups of three transmitters are clearly displayed for identification on four separate traces.

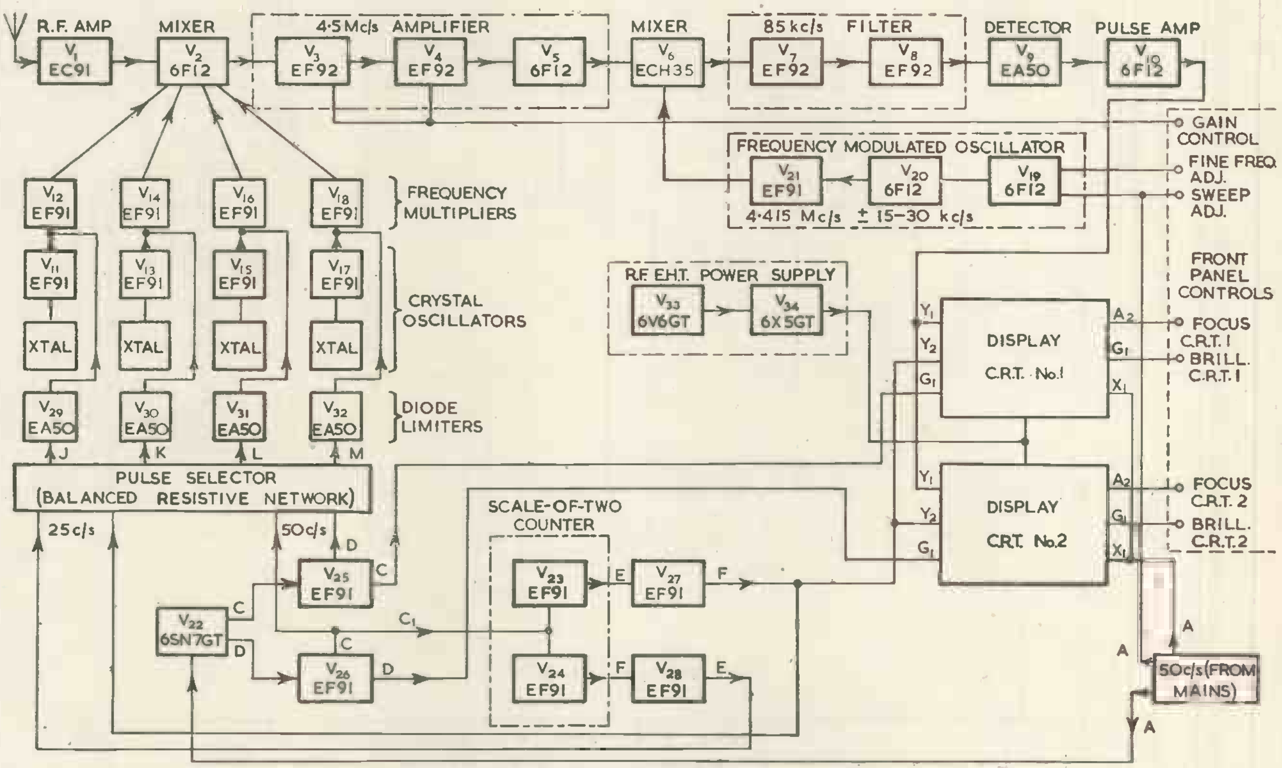


Fig. 2. Block diagram. Panoramic four-scheme monitor

Method of Operation

The conveniently available 50c/s mains waveform is used to synchronize the indicator traces with the keyed oscillators and the frequency-modulated oscillator. The block diagram of Fig. 2 and the various waveforms shown in Fig. 3 illustrate how this is done.

A 50c/s sinusoidal voltage, A, is applied to the X_1 plates of the two indicator tubes. The amplitude is greater than that required for a full-width trace, and only sections P_1, P_2, etc., of the trace are visible. The frequency of the F.M. oscillator is also made to vary according to the sinusoid A, increasing voltage corresponding to increasing frequency. The trace is thus sensibly linear for frequency recording purposes, the major error factor being the applied-voltage frequency-output characteristic of the F.M. oscillator under dynamic conditions. (Receiver response distortion is considered in the section dealing with the main receiver.)

Waveform A is also injected into a double-triode multivibrator V_{22} (Fig. 4) so that synchronized 50c/s 50/50 square waveforms are produced, approximating to waveforms C and D in phase and shape. Two sets of outputs are obtained by using low impedance followers V_{25} and V_{26}, EF91 pentodes strapped as triodes. Waveform C with an amplitude of about 8 volts peak-to-peak is taken from V_{25} cathode and applied to C.R.T. 1 modulator so that the return trace is blanked. Similarly waveform D is taken from V_{26} cathode and applied to C.R.T. 2 modulator, so that increasing voltages on the X_1 plates only appear on C.R.T. 1 and decreasing voltages only appear on C.R.T. 2.

Waveform C is also taken from the anode of V_{26} and, after differentiation, applied to the scale-of-two counter[3]

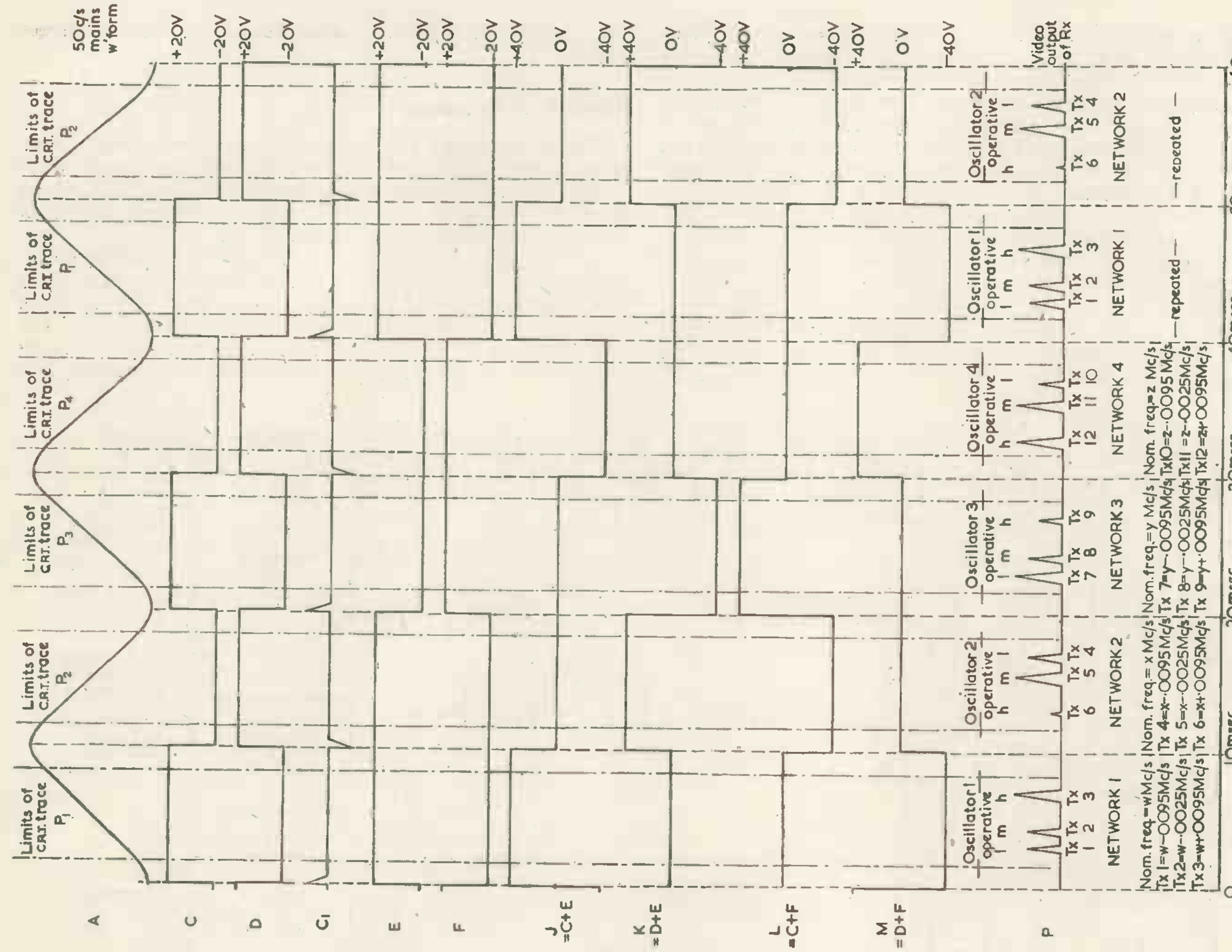
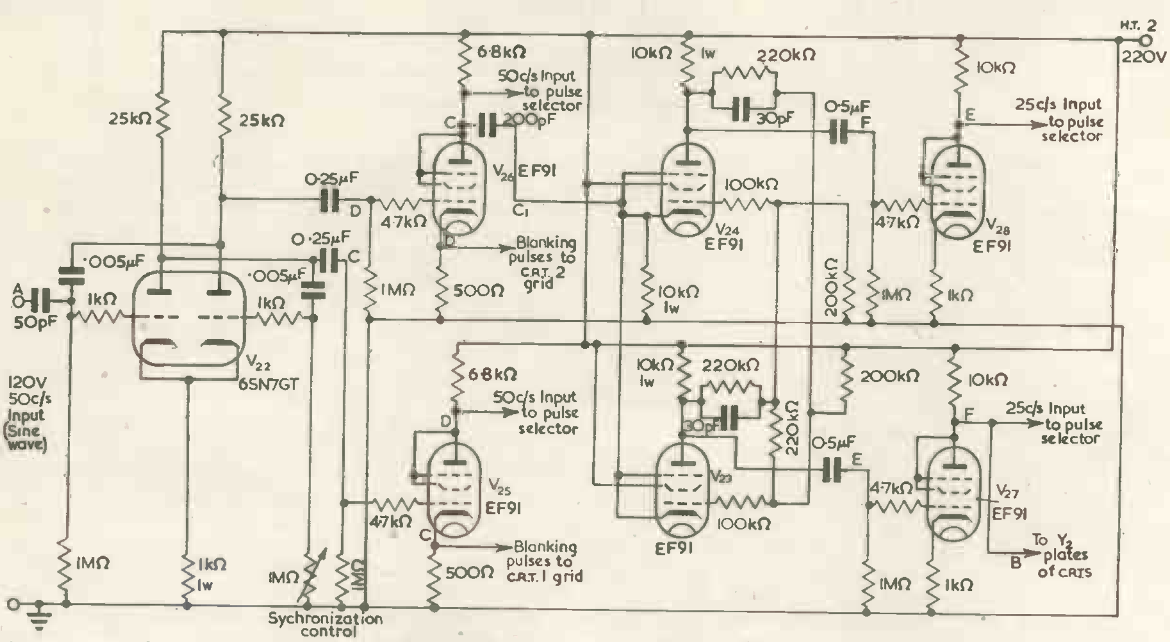


Fig. 3. Waveforms

Fig. 4. Pulse generator circuit



consisting of V_{23} and V_{24}, which responds only to the positive-going peaks on its commoned cathodes and thus generates 25c/s 50/50 square waveforms at the anodes of the same phase and approximately the same shape as E and F in Fig. 3. These two waveforms are fed into the buffer valves V_{27} and V_{28} (which are necessary to avoid unbalance of the scale-of-two counter) and outputs of approximately 80 volts peak-to-peak are taken from the anodes, the waveforms being still sensibly the same as E

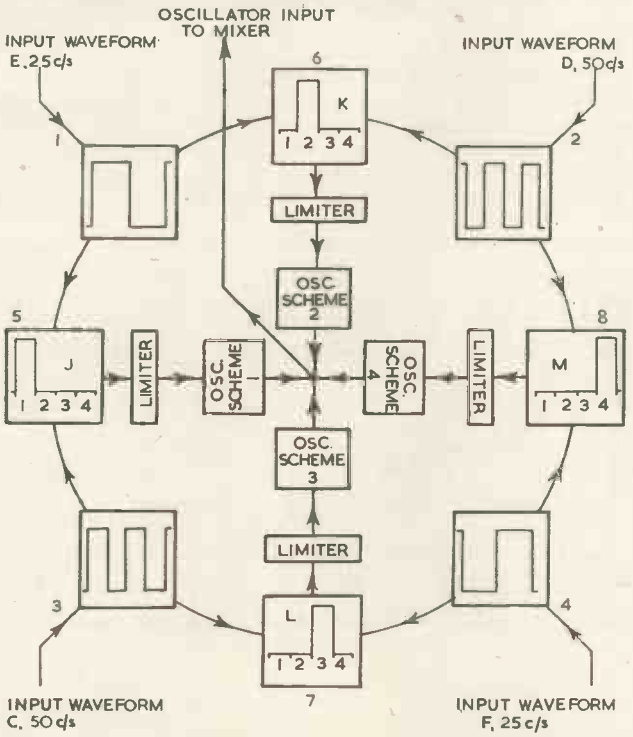


Fig. 5(a). Panoramic four-scheme monitor method of oscillator selection

Normal Case (as described in text)

INPUTS		OUTPUTS			
Point (Diagram 6)	Waveform	Point (Diagram 6)	Connected to scheme	Effective during period	Trace Effective during same period
1	E	5	1	1	Top left-hand
2	D	6	2	2	Top right-hand
3	C	7	3	3	Bottom left-hand
4	F	8	4	4	Bottom right-hand

Second Possible Combination (outputs from Scale-of-Two Counter Reversed).

1	F	5	1	3	Top left-hand
2	D	6	2	4	Top right-hand
3	C	7	3	1	Bottom left-hand
4	E	8	4	2	Bottom right-hand

Fig. 5 (B) Panoramic Four-Scheme Monitor
Illustrating that all schemes will always be represented by the same trace irrespective of the mode of operation of the Scale-of-Two Counter.

and F. Output B of waveform F is taken from the anode of V_{27} and applied to the Y_2 plates of both C.R.T.S, so that during the first cycle of sinusoid A the two one-way traces on C.R.T. 1 and C.R.T. 2 take up a higher position than that occupied during the second cycle. In this way four separate one-way traces are produced. During period P_1 a right-going trace appears on the top half of the left-hand tube C.R.T. 1, during period P_2 a left-going trace appears on the top half of the right-hand tube C.R.T. 2, during period P_3 a right-going trace appears on the lower half of the left-hand tube, and during period P_4 a left-going trace appears on the lower half of the right-hand tube.

In the pulse selector network combinations of the waveforms C, D, E, and F are added to produce waveforms J, K, L, and M, as illustrated graphically in Fig. 3. They are seen to contain a series of 10msec positive pulses recurring every 40msec, i.e. once every 2 cycles of 50c/s. (The negative pulses are ineffective and can be ignored). The method of application is illustrated in Fig. 5(a). The addition of waveforms C and E (of equal amplitude) gives waveform J, and the positive pulse occurring during the first 10msec period is used to key the oscillator section corresponding to scheme 1, the other three oscillators remaining ineffective during this period. Similarly D and E add to give K, the positive pulse occurring during the second period keys the oscillator for scheme 2, and so on, each oscillator in turn being effective for 10msec and the whole cycle being continuously repetitive.

Fig. 6 gives the circuit of the pulse selector which consists of a balancing network of resistors operating as fol-

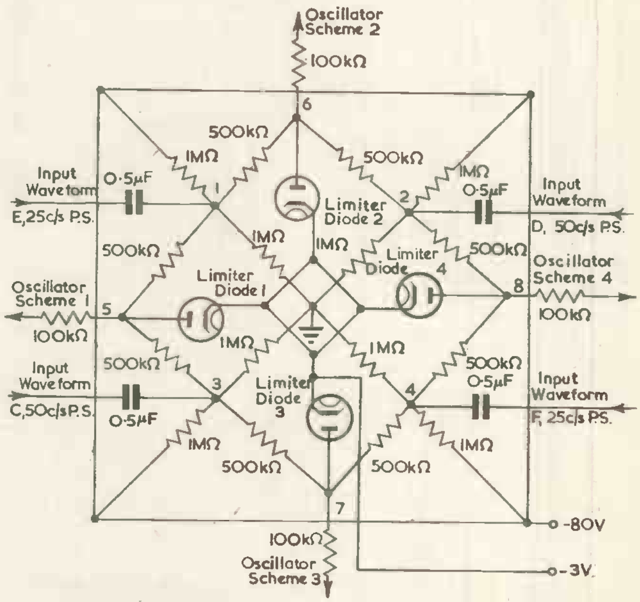


Fig. 6. Panoramic four-scheme monitor pulse selector and distributor circuit

lows. Assuming that there are no A.C. inputs the outer square loop is at -80 volts relative to earth and the two one-megohm potential dividers linking each corner to earth maintain the inner loop, formed by points 5, 7, 8, and 6, at -40 volts. The cathodes of the four limiter diodes are held at -3 volts relative to earth, the diodes are non-conducting and the four controlled oscillator sections are inoperative because the grids of the multiplier valves (V_{12}, Fig. 7) are returned through 100kΩ resistors to oscillator control points 5, 6, 7, and 8. The four input waveforms C, D, E, and F are each of about 80 volts peak-to-peak amplitude, and are taken from the anodes of V_{26}, V_{25}, V_{28} and V_{27} respectively. They are applied to points 3, 2, 1, and 4 through 0·5µF capacitors, and since the inputs are of comparatively low source impedance relative to these points the voltages at these points follow waveforms C, D, E, and F closely. During positive half-cycles these voltages therefore rise to zero. If there were no inputs at the other three points the voltages at the two adjacent oscillator control points would rise by half this value, i.e. to -20 volts, and the associated oscillators would remain inoperative. When, however, positive half-cycles are applied simultaneously to two adjacent input points, both rise to zero volts, and the oscillator control point linked to both these points by 500kΩ resistors follows until the associated limiter diode conducts. The peak positive voltage applied to the grids of the oscillator multiplier valves is thus clamped at about -3 volts.

In Fig. 3 if C, D, E, and F represent the amplitudes of these waveforms appearing at the oscillator control points (i.e. one-half the input amplitude), waveforms J, K, L, and M represent the amplitudes of the combination waveforms which are obtained when each adjacent pair is added in this way.

The limiter diodes also serve to make the circuit insensitive to input voltage variations due to valve deterioration, etc., and for this purpose input waveforms C, D, E, and F are made about 100 volts peak-to-peak amplitude. (The high series resistors prevent the limiter currents being excessive, and the only effect is the lowering of the mean potential of the loop 5-7-8-6 by a negligible amount.) The circuit is then completely non-critical even of extreme variations in its working conditions, and no adjustments or valve changes have been necessary in any of the pulse circuits during the period of two years in which the equipment has been in service.

The use of a scale-of-two counter to provide 25c/s synchronous waveforms gives rise to two possible modes of operation, though these do not affect the indication obtained. This is because the synchronizing "pip" (Fig. 3) can lock to the positive-going or negative-going portion of the 25c/s square waveform, depending on valve characteristics and warming-up times. The table in Fig. 5(b) shows that irrespective of which mode obtains, any network always appears on one particular trace.

Receiver Design

The circuit of the main receiver is given in Fig. 7, and is quite conventional in general detail. Certain design points may be of interest, and these are considered separately.

The Input Stage

The primary requirement for this stage is efficient output to input isolation to prevent excessive radiation from the four keyed oscillators with their associated sidebands. To accept all the incoming frequencies which the receiver normally records, it had to have a bandwidth of at least 10Mc/s, but to cover other possible applications in the 80-90Mc/s band it was decided to increase the bandwidth to 20Mc/s. This led to the adoption of a grounded-grid amplifier stage using the Mullard EC91 valve. The low input impedance due to feedback enables wide bandwidths to be obtained without excessive deterioration in the signal-to-noise ratio[4], and the earthed grid acts as a screen between the output and the input electrodes, thereby reducing oscillator radiation to negligible proportions.

The First Mixer

This stage serves to convert the four bands of frequencies of the four county networks to a convenient standard I.F. value. A Mazda 6F12 steep-slope pentode valve is employed as a single-input mixer[5], both signal and local oscillator voltages being fed into the control grid. The conversion conductance of this stage is varied for each network so that I.F. outputs are obtained which are sensibly equal for all networks even though the input signals may vary widely for different networks due to location, etc. This is done by fixing the bias on the mixer V_2 at the point of maximum efficiency, and varying the oscillator input levels to give the required value of conversion conductance. A negative bias of 3 volts is applied, making the operating point well below the linear region of the I_a/V_g curve, and just above the cut-off point. Under these conditions the oscillator corresponding to the weakest incoming network signals is arranged to have a value of 5 volts peak-to-peak. The stage then operates at maximum gain (i.e., maximum I.F. current component in V_2 anode), because on positive peaks of oscillator voltage V_g becomes $-0{\cdot}5$ volts and the slope (i.e., mutual conductance) attains its maximum value of 10mA/volt. During the reception of a stronger network the corresponding oscillator input is reduced so that on positive peaks V_g is more negative in comparison, and since the mutual conductance at this point is less, giving lower I.F. output, the oscillator input may be adjusted for each network so that the mean I.F. outputs are fairly constant. This allows distant and local networks to be displayed at relatively uniform readability without limiting of the stronger signals taking place.

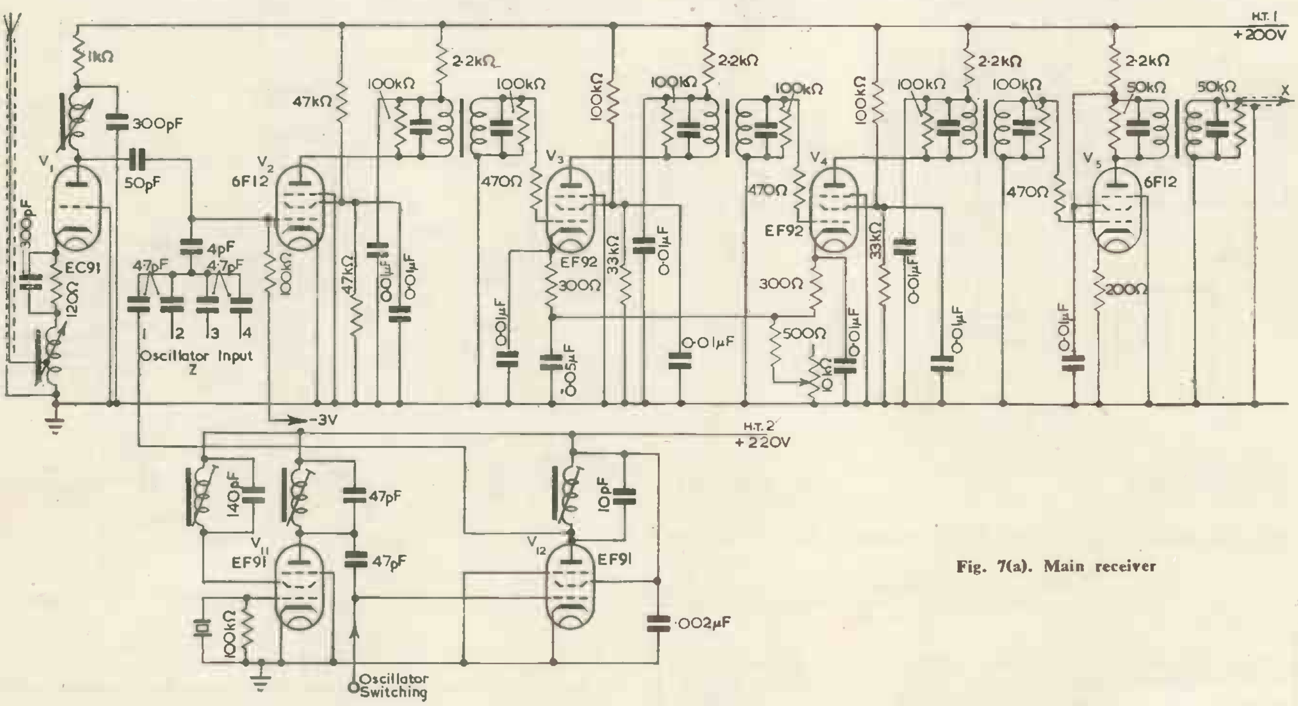


Fig. 7(a). Main receiver

The Local Oscillator Sections

The four oscillator sections are identical except in frequency, each consisting of a crystal-controlled oscillator and a buffer-multiplier valve (V_{11} and V_{12}, Fig. 7). For control a B7G-based crystal in an evacuated envelope is used, the frequency being one-ninth of the final frequency. To avoid drift only the buffer is switched, and since the input to this valve is at one-third of the output frequency there are no spurious responses due to interelectrode capacitance leakage, etc. When a section is operative the control grid of its buffer valve is biased at −3 volts, and switching occurs when this is increased to −40 volts as described earlier. (During one 10msec period every 40msec the grid voltage becomes −90 volts, and while this may seem excessive no trouble has been experienced). The level of the output frequency applied to the mixer may be adjusted either by (a) altering the value of the mixer input capacitor, or (b) by the simple expedient of adjusting the buffer tuning.

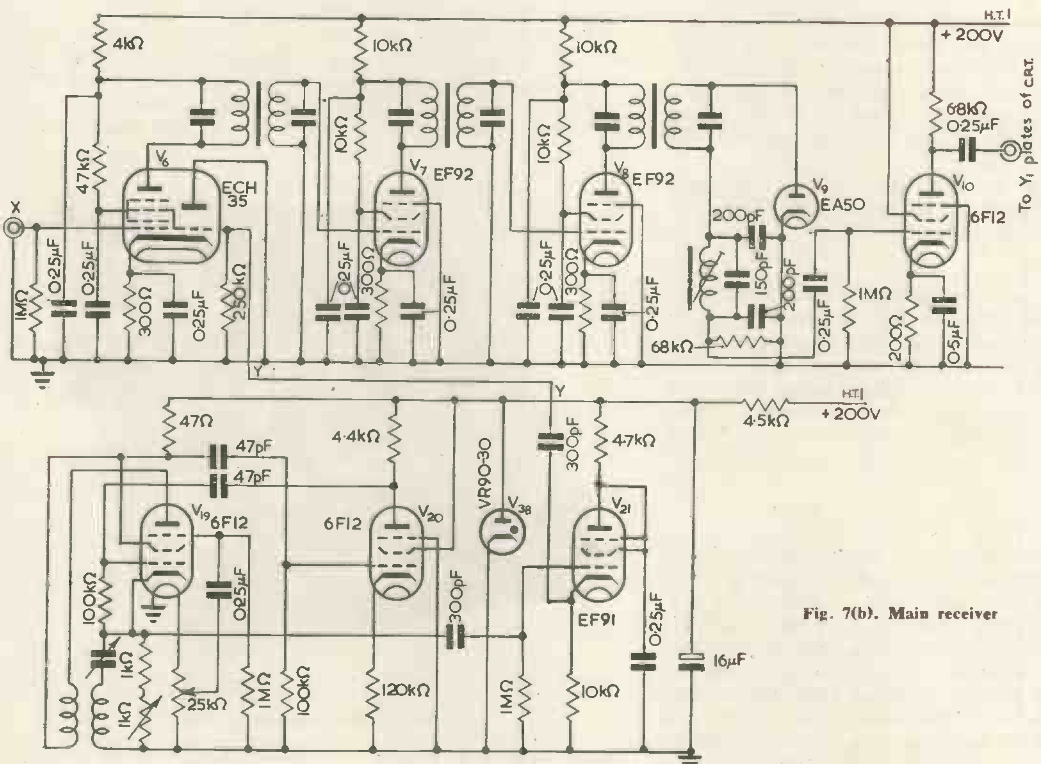


Fig. 7(b). Main receiver

The I.F. Stages

The three amplifying stages at a frequency of 4·5Mc/s use standard miniature transformers with a Q value of 100. Mullard EF92 variable-mu pentodes are used for stages V_3 and V_4, and common cathode bias control is applied for gain adjustment, one of the new miniature high-wattage copper-backed potentiometers being used. This control, of course, affects all signals from all four schemes, its purpose being to prevent overloading on the stronger signals. A.G.C. is not applied because a measure of the relative strength of the recorded signals is required.

The Sweep Oscillator

This is based on the F.M. oscillator design of K. C. Johnson[6]. The two 6F12 pentodes V_{19} and V_{20} comprise the oscillator proper, the tuned circuit elements being placed in series in the cathode of V_{19}, and V_{20} being a phase-invertor linking anode and grid for maintaining oscillation. A coil with approximately unity coupling to the inductive element is connected between the anode and the screen grid of V_{19}, its purpose being to allow the ratio of anode to screen current to alter the inductance and hence the frequency of the oscillator. The anode current to screen current ratio is altered by applying suitable D.C. and A.C. voltages to the suppressor. The centre frequency, or D.C. adjustment, is made by varying the cathode bias potential, while variable sweeps of between ±10kc/s and ±30kc/s are obtained by feeding a variable amplitude 50c/s voltage into the suppressor grid.

The Pulse-Forming Filter

A three-stage filter tuned to a frequency of 85kc/s is used for response pulse forming. The design of this filter is essentially a compromise, due to the conflicting requirements for good display indication. The response pulse in the output has to be clearly defined, separate and distinct from each adjacent pulse, i.e., steep-sided and narrow. A narrow response pulse can only be generated by a narrow bandwidth filter, while steep-sided pulses passing through the amplifier give rise to high frequency modulation components which can only be passed by wide bandwidth stages. The basic relation is that as the oscillator frequency is swept through the correct value relative to the incoming signal frequency, a pulse of signal is produced of duration b/s, where s is the scanning speed in cycles/sec/sec, and b is the bandwidth of the filter. However, owing to the distortion which occurs when the filter bandwidth is less than twice the reciprocal of the time during which the signal is passed by the circuit[7], the actual response pulse is considerably wider. The centre portion of a sine-wave as used in this equipment has an effective repetition frequency of 150c/s, and when the visible band coverage is 40kc/s the scanning speed is 6Mc/s per second. Thus to avoid distortion a bandwidth of at least 12kc/s would be necessary. Filter distortion is considerably reduced when lower frequency linear saw-tooth sweeps are used, but the improvement in readability is not necessary and the simplicity of the 50c/s sine-wave sweep as opposed to a complex low-frequency linear sweep was the deciding factor.

A satisfactory compromise has been reached by adjusting the frequency response of the 85kc/s filter so that the bandwidth is 1kc/s at the −6db levels, increasing to 3kc/s at the −20db levels. This allows two signals 7kc/s apart to be clearly identified even when one is considerably stronger than the other.

Display Unit

The two C.R.T.s used have 2¼in. diameter screens. The E.H.T. applied is 1·5kV, generated by a 6V6GT beam tetrode 50kc/s oscillator, the transformer used being a 5-section standard M.F. choke on a ceramic former, with an extra wave-wound section of Litz wire added as the energizing coil. It is noteworthy that a 6X5GT rectifier used for E.H.T. rectification has proved trouble-free, and the low-capacitance smoothing allows the construction of a very compact supply unit.

Construction

The complete monitor including L.T. and E.H.T. supplies, but excluding H.T. supplies, is built in the form of 10 sub-assembly units mounted on a rigid 3/16 inch aluminium frame measuring 17¼in. wide by 7in. high by 15½in. deep, this being suitable for bolting into a standard 19in. rack. Fig. 8 shows the main details of the layout. The sub-assembly units are designed to simplify maintenance, inter-connexions being made on easily accessible tagboards for power supplies and through "Pye" plugs and sockets for signal feeds.

Power Supply

During the original tests a fully stabilized 240-volt H.T. supply having an impedance of ½ ohm was used. A simple conventional H.T. supply has since been built into the rack and neon stabilization applied to the F.M. oscillator supply. The slight increase in drift due to mains variations, etc., is not troublesome, and did not warrant the use of the fully stabilized unit.

A.C. voltage regulating transformers of the saturated core type having a distorted output waveform cannot, of course, be used with this equipment.

Controls

The eight front-panel controls allow the adjustment of (1) the centring of all schemes on their respective traces. This adjusts the mean F.M. oscillator frequency and is, in effect, a fine frequency control, (2) the spacing of the signals on the trace relative to each other, being the sweep range control, (3) the receiver gain, (4) the sine-wave section used for the trace, by adjusting the synchronization point of the 50c/s multivibrator, and (5) the focus and brilliance of each of the two C.R.T.

Application

Fig. 3(P) shows typical groups of signals as produced and Fig. 1 shows how these are displayed for reading. The signals of each network are presented in increasing frequency order on both tubes, and the long-term stability is such that each can be labelled on the face of the tube for identification. The accuracy and stability of the receiver crystals does not permit absolute frequency monitoring, but a reliable check of frequency drift in any one transmission or network of transmissions can be made by inter-station or inter-network comparison. The frequency spacing of two transmitters can be measured using an audio-frequency sine-wave source of high accuracy to modulate a signal of frequency equal to the mean frequency of the two transmitters, and injecting this signal into the receiver together with the normal input. The two modulation sideband responses can then be made to coincide with the transmitter responses by adjusting the audio-frequency, and the spacing read directly as double the scale reading. In practice this method is used in reverse, for the initial setting-up of the networks. The transmitters are provided with crystal oscillators which can be capacitance tuned over a small range, and these are adjusted until the spacing conforms to pre-determined standards, the audio-frequency standard remaining fixed. The use of external measuring equipment is unnecessary for routine monitoring since the networks, each of known spacing, automatically "calibrate" all the traces and any relevant discrepancy is immediately apparent.

The estimation of carrier power by the comparison of response pulse amplitudes has proved remarkably reliable considering the vagaries of V.H.F. paths. A preventive maintenance routine is carried out for all unattended stations, and the indication of a deterioration in carrier level has often given adequate warning of pending failure. In the same way a decrease in the displacement of the sides of the pulse has enabled the modulation channels to be serviced before actual failure occurred.

Development

Considerable simplification of the circuit is practicable, but since it has proved completely reliable in its present form and quantity production is not required, this was not thought to be justified.

The design of an eight-network monitor working on the same principle has been completed. The resolution obtained is similar to that of the four-network monitor, with a trace repetition rate of 80msec requiring a long-persistence display tube. Eight local oscillator sections are used, and an additional scale-of-two divider allows a 1-8 sequence of pulses to be formed in a cubic-form pulse-selector network. The cathode is taken as the additional control electrode in the display tubes.

The pulse selector network as used in this equipment is believed to be original and possesses several advantages which may find application elsewhere: it is extremely simple compared with other systems for producing a repetitive sequence of pulses, the components are small and the entire unit can be very compact and fault-proof, only natural capacitances are present in the balanced network, thus pulses of high frequency can be generated with negligible distortion, and it is tolerant of supply and component variations.

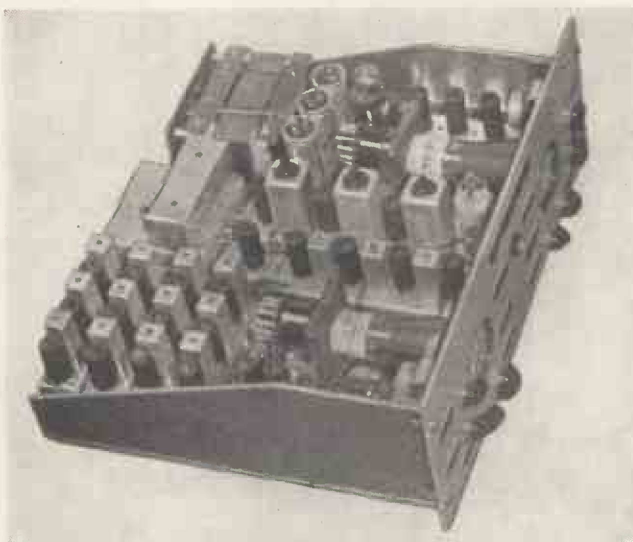


Fig. 8. The complete receiver

Acknowledgments

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A Ten-Channel Pulse Code Telemetering System

By A. J. Bayliss,* B.Sc.

IT is a common requirement that meter readings indicating electrical and other quantities, for example steam pressure, should be displayed at a remote point, very often a central control room, which may be many miles from where the quantity is measured.

Many telemetering systems have been devised requiring communication channels using different numbers of wires and bandwidths over which to transmit the necessary information. The modern trend is to transmit as much information as possible over a channel of a given bandwidth.

The apparatus described has been designed to transmit ten meter readings over one voice frequency telegraph channel, the channels being spaced by 120c/s. Having

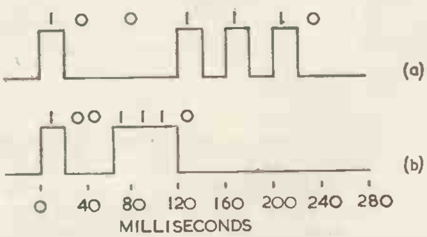


Fig. 1(a). Pulses representing binary number 1001110(78) spaced by 20msec. (b) Same code without spaces showing saving in time

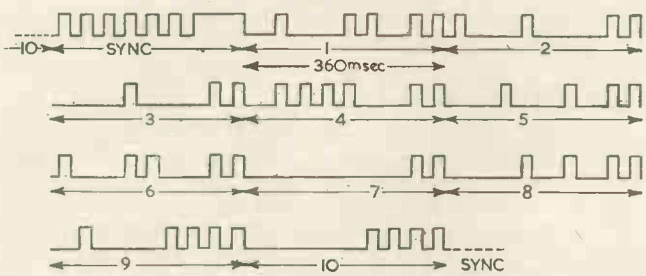


Fig. 2. One complete transmission cycle of 10 meter readings and synchronization signal

chosen the channel bandwidth the maximum signalling speed is also fixed; for 120c/s spaced v.f.t. channels this speed being 80 bauds or 40 cycles per second. A signalling speed less than this maximum is used in practice, namely 50 bauds or 25 cycles per second, to give greater reliability.

The quantities to be transmitted are translated into binary numbers and sent over the transmission channel as rectangular pulses of 20msec duration spaced by 20msec; each binary digit, if present, being represented by the presence of a pulse. A seven digit binary code is used so that 127 discrete levels may be transmitted, in other words a meter reading may be transmitted with an accuracy of better than 1 per cent of full-scale deflexion. Twice the signalling speed could be obtained by omitting the 20msec spaces between the digit pulses, but to do this would add complication to the transmitting and receiving equipment. Fig. 1 shows the binary code 1001110, corresponding to decimal number 78, with and without the spaces, illustrating the saving in time which could be achieved.

When a number of such binary code groups, each corresponding to a different meter reading, have to be transmitted over the single v.f.t. channel it is arranged that they are transmitted cyclically in order. Two extra pulses are always sent at the end of each code group to allow time for relays to operate in the receiver and to synchronize the receiver oscillator even though all the codes to be sent are zero. Fig. 2 shows one complete transmission cycle of 10 meter readings and the synchronizing signal. The first seven pulses in each code group represent the binary number being transmitted, viz. in Fig. 2.

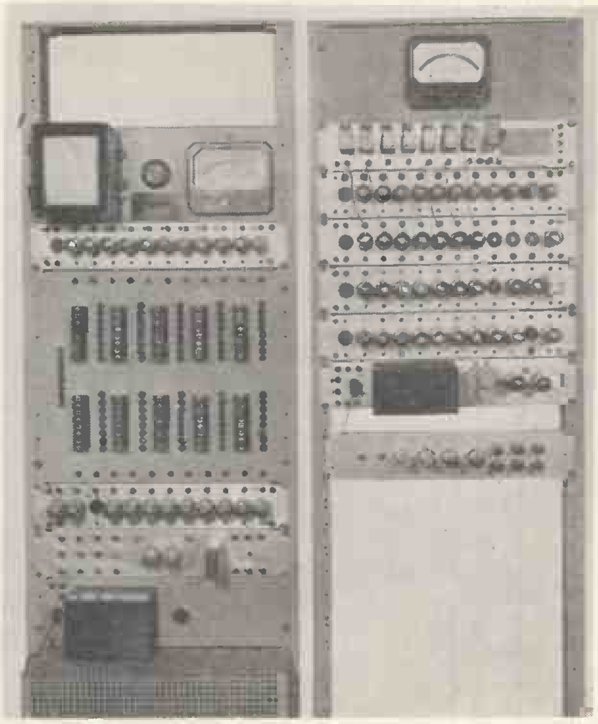


Fig. 3. Showing, on the left, the transmitter and, on the right, the receiver

CODE GROUP	BINARY CODE	DECIMAL NUMBER
1	0100110	38
2	1001000	72
3	0001000	8
4	0011110	30
5	0010010	18
6	1001100	76
7	0000000	0
8	0001010	10
9	0100011	35
10	0000011	3

The synchronization signal will be seen to consist of 6 pulses followed by a longer pulse. The characteristic long

* *Research Laboratories of The General Electric Co. Ltd.*

pulse is used to inform the receiver when the beginning of code group No. 1 is approaching, so that the receiver distributors may be synchronized with those at the transmitter. The leading edge of every line pulse transmitted is also used at the receiver to synchronize the receiver oscillator.

After multiplexing and transmitting the code groups as outlined they must be sorted and decoded at the receiver, the ten transmitted meter readings being indicated on ten separate meters.

In the equipment which has been developed the translation of the quantities to be transmitted into a binary code is done by a relay or other electro-mechanical coder. At the receiver another relay set acts as a decoder. All multiplexing and pulse distribution, however, is performed by cold-cathode tubes in conjunction with one or two Carpenter high speed relays. In this way the portion of the equipment subject to continuous operation is electronic and that part which operates less frequently employs relays. This combination leads to a system of high reliability and long life.

The Coder

The coder works in conjunction with an electro-mechanical balance such as is shown in Fig. 4. Two coils

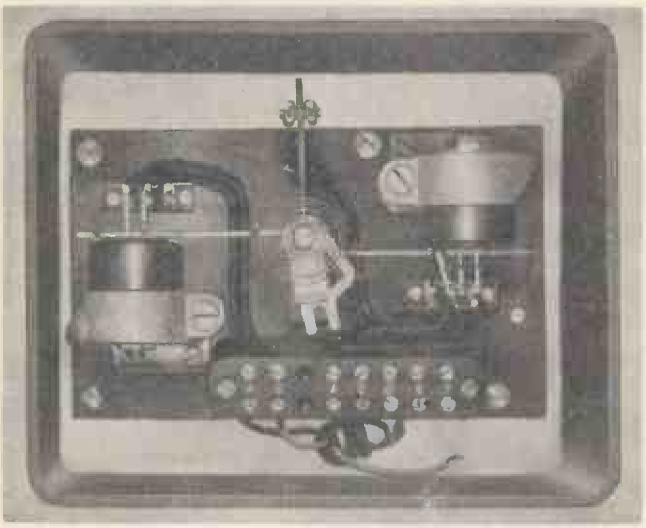


Fig. 4. Electro-mechanical balance for use in conjunction with relay coder (*Manufactured by Messrs. Evershed and Vignoles, Ltd.*)

move in the fields of permanent magnets, each rather like the voice-coil of a loudspeaker. The coils are mounted at each end of an arm which may be centred by means of a hair spring. The arm carries an electric contact.

The quantity to be coded (e.g. direct current) is fed through one coil of the balance. The other coil, called the balance coil, is fed with combinations of definite magnitudes of current from the coder as required. These definite quantities of current are arranged in decreasing powers of two, viz. 64, 32, 16, 8, 4, 2 and 1 unit. If a non-electrical quantity is to be coded, e.g. oil pressure, then the first coil would be replaced by a pressure gauge, the mechanical torque produced being balanced by currents passed through the balance coil by the coder.

The action of the coder is as follows. On receipt of a start signal the coder first passes 64 units of current through the balance coil (full-scale deflexion being 127 units). This current will either break the contact on the balance arm if the torque produced is too great or leave the contact made if the torque is too small. If too large the coder will next try passing 32 units through the coil and so on.

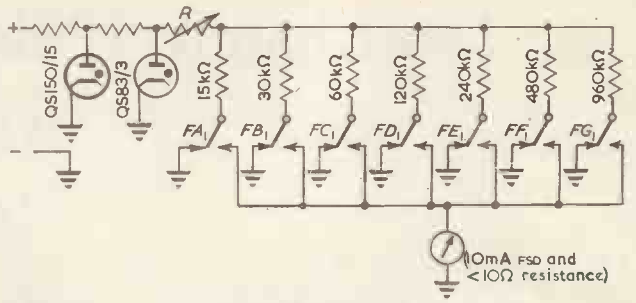


Fig. 5. Decoder circuit

If the applied current is too small then that current is kept passing through the coil by the operation of one of a set of seven relays and the next smaller current is then tried. In this way a selection out of the seven relays is left operated according to which quantities of current are required to restore the balance. The time taken to encode a reading is about 2½ seconds.

The Decoder

The decoder consists of a series of seven telephone type relays. As will be explained later they are arranged so that an operated relay represents the presence of a digit. The simplified circuit is shown in Fig. 5. Relay contacts FA_1 to FG_1, shown in the relaxed condition, allow current to flow either direct to earth or through the meter to earth. Thus a constant current is taken from the supply which is held constant by a high stability reference tube type QS83/3. The variable resistance R enables the full-scale meter deflexion to be set up and allows for supply voltage variations when tubes are changed. It will be seen that the seven high stability resistors associated with the contacts FA_1 to FG_1 allow quantities of current arranged in powers of two to pass through them.

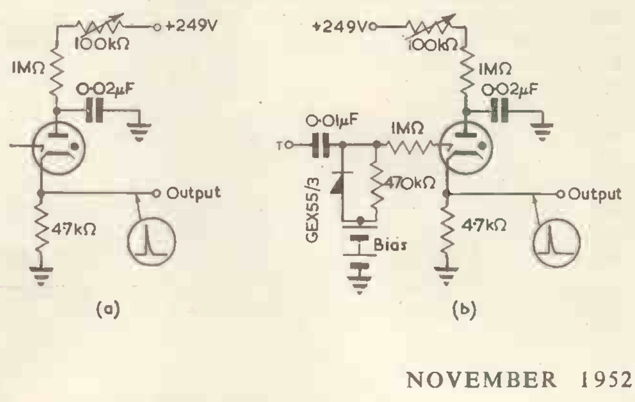
A more detailed description of how the decoders are operated is given in the section dealing with the receiver.

Transmitter Multiplexer

The transmitter multiplexer consists of the second, third, fourth and fifth panel down from the top of the left-hand rack shown in Fig. 3. The bottom panel is a power supply. A block diagram is shown in Fig. 8.

The transmitter is controlled by a 25c/s master oscillator on the left-hand side of the panel above the power supply. A cold-cathode tube is used as a relaxation oscillator, as shown in Fig. 6(a). H.T. is supplied from three QS83/3 high stability reference tubes connected in series, and the tube is enclosed in a light tight box and provided with constant illumination from an under run tungsten lamp. This latter precaution is essential because the tube anode breakdown potential is erratic if the tube

Fig. 6(a). Transmitter oscillator circuit. (b) Receiver oscillator circuit with synchronization arrangement



is run in the dark and also depends on the light intensity falling on the tube. By taking these precautions, oscillators with a frequency stability of better than 1 part in 100 can easily be made.

Positive output pulses are taken from the cathode circuit of the oscillator and fed to a digit distributor consisting of nine cold-cathode triode tubes. It is arranged that each pulse supplied from the oscillator strikes the next tube along the row which then extinguishes the previous tube. The circuit of three stages of the distributor is shown in Fig. 7. Assume that the first tube is struck, then the cathode of V_1 will be at a positive potential relative to earth. The trigger of V_2 is connected to the cathode of V_1, it is therefore biased positive, and the circuit components are chosen so that this bias is less than the trigger-

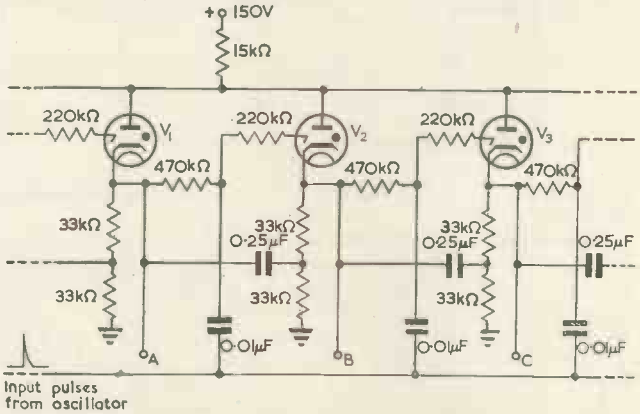


Fig. 7. Distributor circuit. Output pulses, distributed in time, are obtained from the output terminals A, B, C, . . . etc.

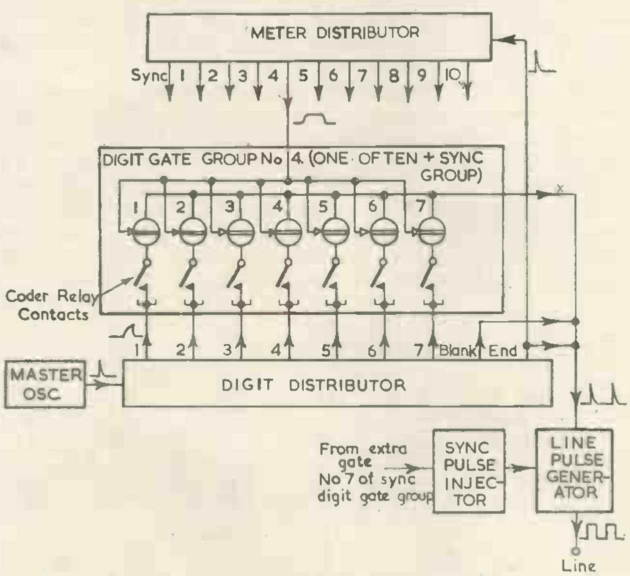


Fig. 8. Telemetering transmitter multiplexer

ing potential of the tube. The incidence of an input pulse from the oscillator, in itself insufficient to trigger an unbiased tube, will strike V_2 which has a positively biased trigger. When V_2 strikes the rise in its cathode potential is communicated to the cathode of V_1 through the $0{\cdot}25\mu F$ capacitor and at the same time the anode potential of V_1 is lowered owing to the increased current flowing in the common anode load resistor when V_2 struck. These two effects lower the potential across the main gap of the tube V_1 to below the extinction value and V_1 goes out. The process is repeated and the next oscillator pulse will strike V_3 and extinguish V_2 and so on.

As each tube in the distributor strikes in turn, output pulses, distributed in time, are obtained from the output terminals A, B, C etc., each of 40msec duration.

When the last tube in the digit distributor strikes, a pulse is fed into an eleven-stage meter distributor, being the third panel down on the left-hand rack in Fig. 3. The meter distributor circuit is similar to that just described, and the tubes are struck in succession once per digit distributor cycle. Positive output potentials are obtained in turn from the meter distributor output terminals, each lasting for a period of 360msec, that is nine times the length of the digit distributor output pulses.

It will be seen from Fig. 8 that the meter and digit distributor output pulses are fed to groups of digit gates. Each group consists of seven cold-cathode diode gate circuits, one of which is shown diagrammatically in Fig. 8. In the diagram the group of gates is shown connected to number 4 meter distributor output and each gate of the group is fed from a digit distributor output. The gate is such that the coincidence of potentials from both distributors causes an output to be produced on the common out-

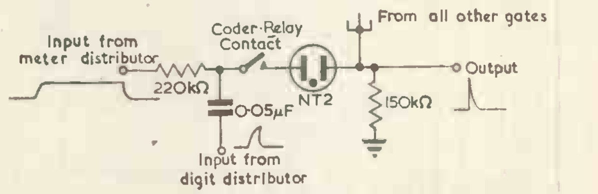


Fig. 9. Cold-cathode diode gate circuit

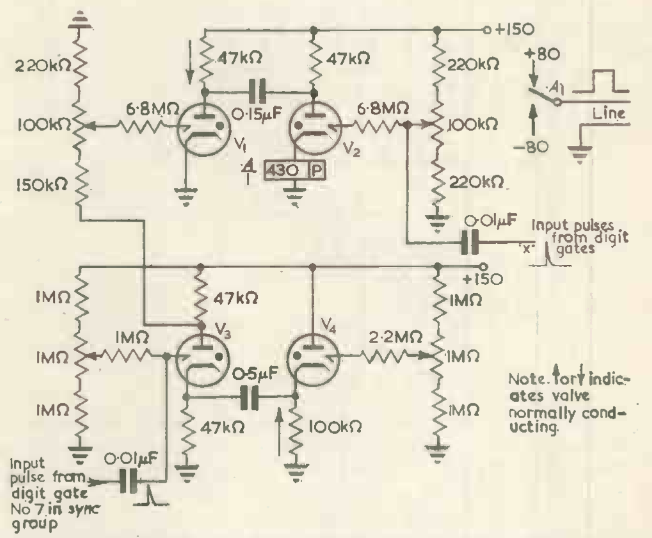


Fig. 10. Circuit showing the line pulse generator above, and the synchronization pulse injector below

put wire x. The contacts on the coder relays which signify whether a certain binary digit is present in the quantity encoded are connected to bring the gate circuit into operation if required. Fig. 9 shows a typical diode gate circuit.

It will be appreciated that the two distributors act in conjunction to alert and scan over each group of digit gates in turn and if a coder relay contact is closed a pulse will be sent out at its proper position in time along the common output wire x. The time taken to scan over ten coders and the synchronizing channel is 11 × 360msec, i.e. just under 4 seconds.

The shape of the pulses coming from the digit gates is unsuitable for sending out to a telegraph circuit. They are therefore fed into a line pulse generator circuit which accepts these short pulses and gives an output in the form of a square wave with unity mark to space ratio. The circuit used, shown in the upper half of Fig. 10 is a cold-cathode tube monostable multivibrator with a telegraph relay in the cathode of the normally off tube V_2; V_1 is normally conducting and when a pulse is applied to the trigger of V_2 the tube strikes and operates the line relay *A*. When V_2 strikes, the fall in anode potential is communicated through the anode coupling capacitor to the anode of V_1 and it is arranged that the fall is sufficient to extinguish V_1. The anode potential on V_1 then rises exponentially until V_1 strikes again extinguishing V_2 and releasing relay *A*. The bias and trigger load resistors are chosen so that V_2 does not strike when its anode has risen in potential to a level equal to the supply voltage. V_2 can only strike when a pulse is re-applied to its trigger.

The synchronization pulse is one of longer duration than the ordinary 20msec line pulses. This long pulse is inserted in the pulse train by means of a synchronization pulse injector circuit. The circuit shown in the lower half of Fig. 10 is another monostable multivibrator which is triggered by the output from an extra number 7 digit gate in the synchronization digit gate group. The other gates

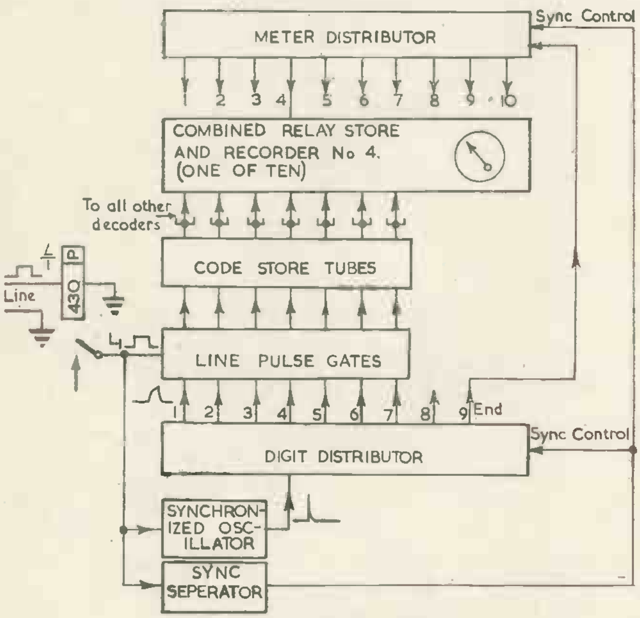


Fig. 11. Telemetering receiver

in the synchronization group are the same as those in the other ten groups with the exception that the coder relay contacts are omitted and replaced by a direct connexion so that these gates always operate on receipt of a pulse from the digit distributor.

The synchronization pulse injector circuit is arranged to give a 100msec negative going output pulse from the anode of V_3 when triggered; V_4 is the normally conducting tube. The anode of V_3 is coupled directly into the trigger circuit of V_1 in the line pulse generator so that when V_3 is conducting the trigger potential of V_1 is lowered. When an output pulse is applied along wire x to the line pulse generator tube V_2 will strike and relay *A* operate as usual. However, a simultaneous triggering of V_3 will reduce the bias on the trigger of V_1 so that V_1 cannot restrike after the normal 20msec interval. Only when the anode potential of V_3 has risen again 100msec later can V_1 restrike and relay *A* be released. In this way a 100msec pulse is sent to line its leading edge corresponding to that of pulse number 7 in the synchronization code group.

The Multiplex Receiver

A block diagram of the receiver is shown in Fig. 11. Digit and meter distributors similar to those in the transmitter are used, driven from a synchronized relaxation oscillator. The oscillator is shown in Fig. 6(b). Square line pulses, derived from the receiver line relay contact, are differentiated by the series capacitor and shunt resistor in the trigger circuit. The germanium rectifier eliminates the negative going pulses which would be derived from the trailing edges of the line pulses. The incidence of these synchronizing pulses on the trigger ensures that the tube strikes in synchronism with the leading edges of the incoming line pulses. In practice the receiver oscillator is

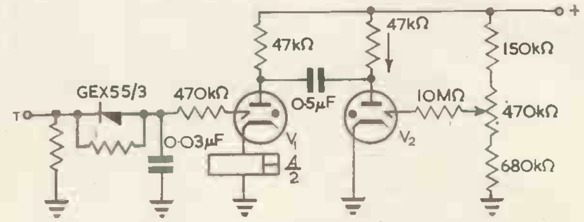


Fig. 12. Synchronization pulse separator circuit

adjusted to run very slightly slower than the transmitter oscillator.

Besides ensuring that the receiver and transmitter oscillators are synchronized it is also necessary to synchronize the distributors. This is done at the beginning of each transmission cycle by the long synchronization pulse already mentioned. At the receiver all line pulses are fed into the synchronization pulse separator circuit, shown in Fig. 12, at terminal T.

V_1 and V_2 form a monostable cold-cathode tube multivibrator circuit in which V_2 is normally conducting. A Siemens double contact high-speed relay *A* is connected in V_1 cathode circuit. The trigger circuit of V_1 is fed from an integrating circuit consisting of the germanium crystal rectifier GEX55/3 in parallel with a resistor and the shunt 0·03μF capacitor. Positive line pulses applied to the input terminal T will charge the capacitor slowly through the back resistance of the germanium rectifier and the parallel connected resistor, but the capacitor will discharge quickly in the time between one line pulse and the next. The incidence of the long synchronization pulse will allow the trigger potential to build up to a high enough value to strike the tube. Relay *A* will then operate for a few milliseconds until the multivibrator reverts to its stable position. In this way relay *A* is only operated (once every

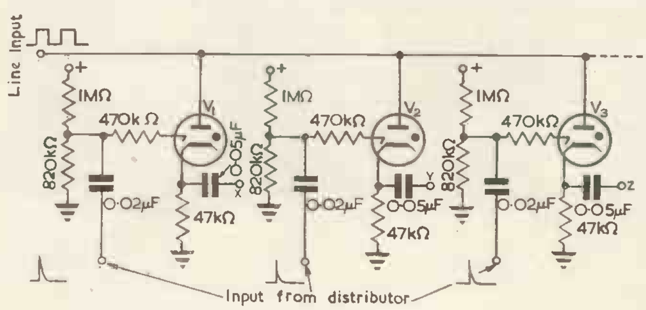


Fig. 13. Line pulse gate circuit
Output pulses obtained from points X, Y, Z, . . . *if pulses present on line.*

4 seconds) by the long synchronizing pulse at the beginning of each transmission cycle.

The operation of relay *A* extinguishes all the tubes in the digit and meter distributors and then immediately strikes the first tube in the meter distributor and the end tube in the digit distributor. This takes place in the space period preceding the incidence of the first pulse in the first meter reading code group so that the two distributors are in the correct condition at the beginning of each transmission cycle and both in phase with those at the transmitter.

Incoming line pulses are fed, Fig. 11, to the anodes of a series of 7-line pulse gates. The trigger electrodes of the gates are fed in turn with voltage pulses from the digit distributor. Circuit values in Fig. 13 are chosen so that the trigger gaps breakdown on application of the distributor pulses, but the main gap only breaks down if there is a coincidence of trigger breakdown and anode voltage (i.e. mark condition on the line). When the main gap strikes the tube cathode potential will rise and a positive output pulse will be obtained corresponding to a mark condition on the line. These output pulses are fed to the trigger electrodes of a group of seven code store tubes. In this way the incoming code signal is set up on seven cold-cathode tubes, a struck tube representing a mark and an extinguished tube a space.

As the store will only accommodate one seven-digit code, it is necessary to transfer the code from the tube store and leave the store empty before the next code is received. Also all the code must be transferred at the same moment and not sequentially as this would introduce large meter reading fluctuations during transfer. This transfer takes place during the time interval of 80msec occupied by the

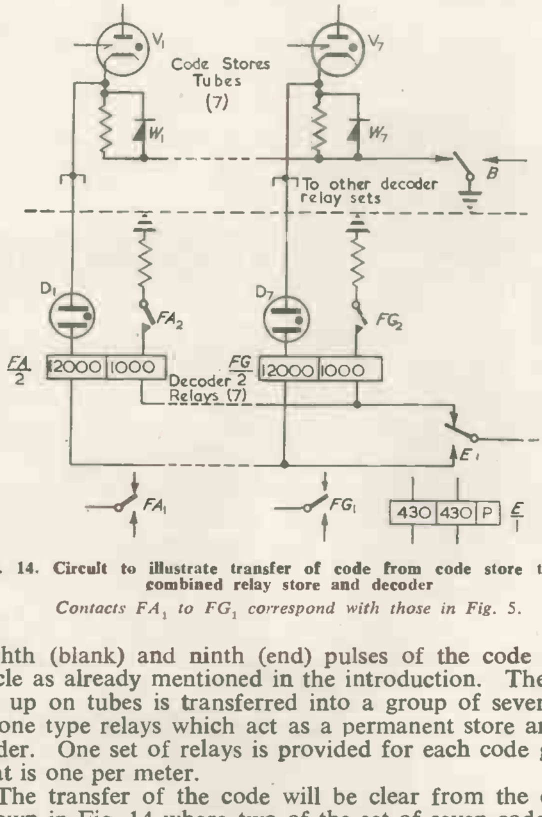


Fig. 14. Circuit to illustrate transfer of code from code store tubes to combined relay store and decoder

Contacts FA_1 to FG_1 correspond with those in Fig. 5.

eighth (blank) and ninth (end) pulses of the code group cycle as already mentioned in the introduction. The code set up on tubes is transferred into a group of seven telephone type relays which act as a permanent store and decoder. One set of relays is provided for each code group, that is one per meter.

The transfer of the code will be clear from the circuit shown in Fig. 14 where two of the set of seven code store tubes together with two of one of the ten sets of seven relays *FA* and *FG* are shown.

Associated with each set of relays is a high-speed polarized relay *E* which operates at the end of the digit distributor cycle, that is when the code has been set up in the tube code store. Relay *E* is operated by the coincidence of a positive potential from the meter distributor and a negative potential from an extra cold-cathode tube which operates at the same time as the seventh tube in the digit distributor so that only the *E* relay in the desired relay decoder set operates corresponding to the meter distributor tube which is struck.

When the relay *E* operates for a few milliseconds a combination of the negative potential applied by contact E_1 and the positive potential supplied by a struck tube in the tube code store will cause the cold-cathode diode D_1, say, to strike, so operating relay *FA*. When the high-speed relay *E* releases relay *FA* will then self hold through contact FA_2. In this way the code set up on the tube code store is transferred to the relay store, an operated relay representing a mark and a relaxed relay a space. When the next code group destined for a particular decoder appears four seconds later a relay will release if a space is to be recorded but remain operated if another mark is to be recorded. Relay wear is minimized in this way. The relay contact B_1 shown in Fig. 14 is operated when the end tube in the digit distributor strikes and extinguishes all the tubes in the tube code store in readiness for reception of the next code group. The rectifiers W_1, etc., shown in Fig 14 are inserted across the code store tube cathode load resistors to prevent negative inductive voltage surges from the relays lowering the store tube cathode potentials to a point which would cause trigger and anode to cathode breakdown.

Advantages and Disadvantages of the System

This telemetering system has the advantage of using a pulse code system of transmitting a quantity, which enables transmission circuits with a high noise level to be used. The transmission of ten meter readings along a voice frequency telegraph channel is very economical in bandwidth. Further advantages of reliability and ease of maintenance accrue from the use of cold-cathode switching tubes which are known to have long life and give a visible light output when operating so that faults are quickly traced.

A disadvantage of using a pulse code system is that very large extraneous noise pulses or breaks in the transmission circuit can cause an error of 50 per cent of full-scale deflexion if they occur at a time when the "heaviest" digit is being transmitted. It is unlikely that such an error will persist, however, and a checking system has been devised so that if an error occurs during one complete cycle a warning lamp lights. If the error persists for more than two cycles (eight seconds) an urgent alarm is given.

NEW PREMISES FOR THE BBC

Since September 22, when the new schools broadcasts term began, programmes have been originating from the new building recently taken over by Schools Broadcasting Department, Nos. 1 and 1A Portland Place. The new building contains, in addition to offices, 5 studio suites designed and constructed to meet schools broadcasts requirements. There are three general purpose studios, two talks studios, their associated control cubicles, an "echo room" and an apparatus room.

The technical equipment, built to BBC design, enables each studio suite to function as a self-contained unit. Each studio has its own control cubicle containing a desk on which are mounted all the necessary operational controls. In accordance with modern practice each microphone has its own amplifier. The outputs of these amplifiers are fed first to a mixer unit on the control desk where they can be selected individually, or combined, as required, and then to a main amplifier, which is also controlled on the desk. Provision is made for adding artificial echo in varying amounts to any of the microphone or gramophone points. The amplifiers and control relays are grouped together in apparatus cabinets, one of which is associated with each studio suite.

Means are also provided to link the outputs of three of the other studios to the control desk in the cubicle of Studio 5, which then acts as a master control position, and has its talk-back, cue light controls, and similar facilities, extended to them. Such linking arrangements augment the usefulness of the studios and permit more ambitious productions to be handled.

The installation is of special interest in that once the studio equipment has been set up ready for use it can be switched on and off as required from the main control room in Broadcasting House. This necessitated the collaboration of the G.P.O. who provided the cables interconnecting the two buildings.

BBC New Automatic Unattended Transmitter Technique

(Part 2)

By F. A. Peachey*, M.I.E.E.; R. Toombs*, B.Sc., A.M.I.E.E., and C. Gunn-Russell*, M.A.

THE previous section of this article described the principle of the devices used to provide automatic monitoring over the line link connecting the parent station to its satellite unattended transmitter. This automatic monitoring embraced the part of the system existing between the programme signal source at the parent station and the programme input terminals of the transmitter. This monitor has executive action over the complete system so that if the line link becomes defective the transmitter will be closed down until further tests indicate that the trouble is likely to have cleared.

The transmitters are dealt with in a slightly different way, and that is one of the reasons for dividing the overall automatic monitoring into two parts.

Whereas there is no spare line immediately available for replacement purposes and one fault produces complete breakdown, there are several transmitters, paralleled to work together, and a fault on one of these merely results in a decrease in total output power.

In order to make full use of the safety factor, established by this multiplicity of transmitters, it is necessary to monitor each separately so that the defective unit can be removed.

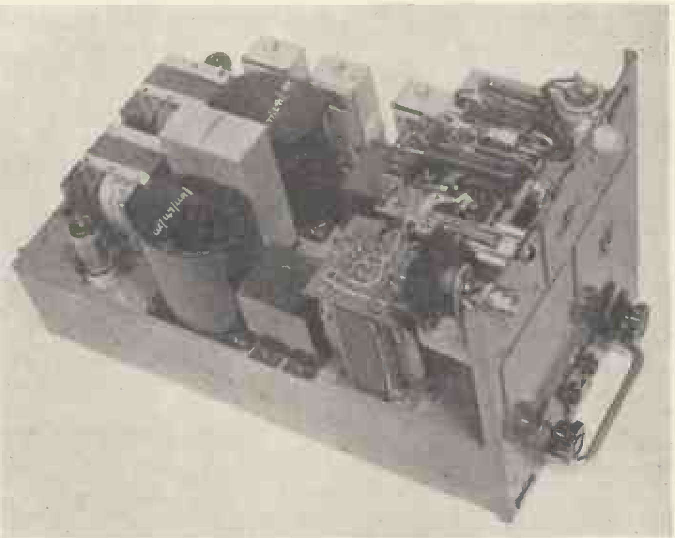
This may be done with one monitor examining each unit in turn on a sequential basis, or by a separate monitor permanently associated with each transmitter. The choice between these systems really depends upon simple economics. In the one case only one monitor is required plus some automatic sequencing gear. However, it also results in each transmitter being kept under examination for only a part of its operating time. In the other case each transmitter requires its separate monitor but the transmitter is watched for the whole time. If the monitor can be of a relatively small and cheap design, the separate monitor per transmitter has obvious advantages. It not only gives full monitoring and saves the complexity of sequencing gear, but also avoids the need for self-testing to ensure that any executive action is legitimate. The separate monitor, if reasonably simple and robust, may be regarded as a part of the transmitter, and if the monitor fails, that transmitter can be regarded as defective.

For this reason, a relatively simple and reliable monitoring unit[3] has been designed which should not contribute seriously to the breakdown incidence of the transmitter unit. One such monitor has been attached to each transmitter.

Of course, some price is paid for the extra robustness and simplicity. It cannot be so complete in its discrimination as the earlier and more elaborate monitors which have been designed to cover both line link and transmitter. On the other hand, the need for such completeness in discrimination is considerably offset by the restricted nature of the faults it will normally be expected to detect, and by the "dilution" which results from combining the outputs of several transmitters.

The overall monitor should deal with

(1) Change of transmission equivalent (including breaks in transmission).
(2) Noise—which includes crosstalk over the complete audio band.
(3) Frequency amplitude response.
(4) Non-linear distortion (such as overloading, etc.).



Automatic monitor unit for transmitters at unattended stations.

A monitor watching over a transmitter is not likely to experience faults such as frequency response defects, audio frequency crosstalk, etc. The most likely fault is nonlinearity and, to a lesser degree, noise. Such noise would nomally comprise excessive hum or crackles. Complete breakdown, or decrease in gain, should, of course, be included as a distinct possibility.

Furthermore, it should be remembered that if these transmitters are to be unattended, no assistance can be given in clearing minor or marginal troubles until the routine check is made, perhaps monthly, so the demands on monitor sensitivity are relatively lower.

The monitor which will be installed in many of these unattended stations has therefore been designed to have primary discrimination on non-linearity, and a secondary action to guard against undue noise, breaks and small reductions in gain and large increases in gain.

Its operation characteristics are approximately as follows:—

(1) Non-Linearity

Operation on a compression in audio frequency signal amplitude of 10-15 per cent, based on rectification of the audio signal in a circuit, with a forward time-constant of approximately 20 milliseconds (maximum sensitivity at 400c/s).

(2) Noise

Operation on noise graded as follows. (Reference level below the equivalent of 100 per cent modulation).

50c/s	−20db
100c/s	−27db
200c/s	−30db

* *Designs Department, BBC Engineering Division.*

(3) CHANGE IN GAIN

(Audio signal in—audio signal out).

Reduction in Gain

50c/s	10·0db	taken near to 100 per cent modulation
100c/s	5·0db	
250c/s	2·5db	
1000c/s	1·5db	
3000c/s	2·5db	
7000c/s	6·0db	

Increase in Gain

About 10db over main part of range—not considered important.

The circuits operating on non-linearity and noise are practically independent so that they may each be pre-set to the required values.

Normal programme loading on the transmitter will cause fairly frequent compressions on the inawrd peaks of modulation for short periods. This is inevitable with any such transmitter unless peak choppers or special limiters are fitted earlier in the programme circuit. The monitor is therefore desensitized above 95 per cent modulation so that no such signal, however distorted, can cause operation. This is proper, as undue distortion from this cause cannot be classified as a transmitter fault.

In studying the approximate performance given above, it should be remembered that in most cases, three transmitters will be used in parallel. This means that a fault on any one, producing 15 per cent compression and the consequent non-linear distortion, will affect the overall combined output by only about one-third this value, probably representing less distortion than that produced by normal occasional overloading. The basic diagram of the circuit is shown in Fig. 7. The two parts of the circuit, that covering compression—or non-linearity—and that covering expansion—or noise—are shown partially separated, for general clarity. The two circuits joined together, are contained in a single small unit which fits into the transmitter cabinet. The complete unit, including these two circuits, associated relays, power supplies and the detector (for producing the A.F. output signal from the transmitter output) measures 8in. × 9in. × 15in., and is shown in the accompanying photograph.

The upper part of Fig. 7 shows the section dealing with non-linearity, etc., and it will be seen that it comprises two rectified sources of programme signal, the one derived from the transmitter input and the other from its output. The time-constant features are not shown. The currents from these two sources normally balance each other in the differential relay (RL_1). This relay is side-stable so that if the currents are substantially equal, it is in the non-operated condition.

Bias supply "2" opposes current flow from the output rectifiers until the programme signal has reached a substantial value, and this prohibits the action of this part of the monitor at low signal values. It also provides better loading conditions on the amplifier valves supplying the monitor.

Bias supply "1" is such that MR_1 and MR_2 do not conduct until the programme signal reaches a value, which would modulate the transmitters to a depth of about 95 per cent. On normal programmes below this value the rectifiers represent high impedance shunts across the relay windings. On higher volumes of programme the rectified signal becomes equal to the voltage of Bias 1, MR_1 and MR_2 conduct and the relay is effectually shunted by a low impedance. The monitor is thus desensitized for audio frequency amplitudes exceeding 95 per cent modulation and action of the monitor is prohibited if "normal clipping" occurs.

Audio frequency weighting is introduced by networks A_1 and A_3 and it will be seen from Fig. 8 that the weighting is heavier on the transmitter output side. This not only proportions the operation of the monitor to correspond roughly to audible distortion, but avoids undue sensitivity to small variations in the frequency response of the transmitter, which inevitably occur at the lower and upper frequencies.

The section of the monitor used for detecting noise is

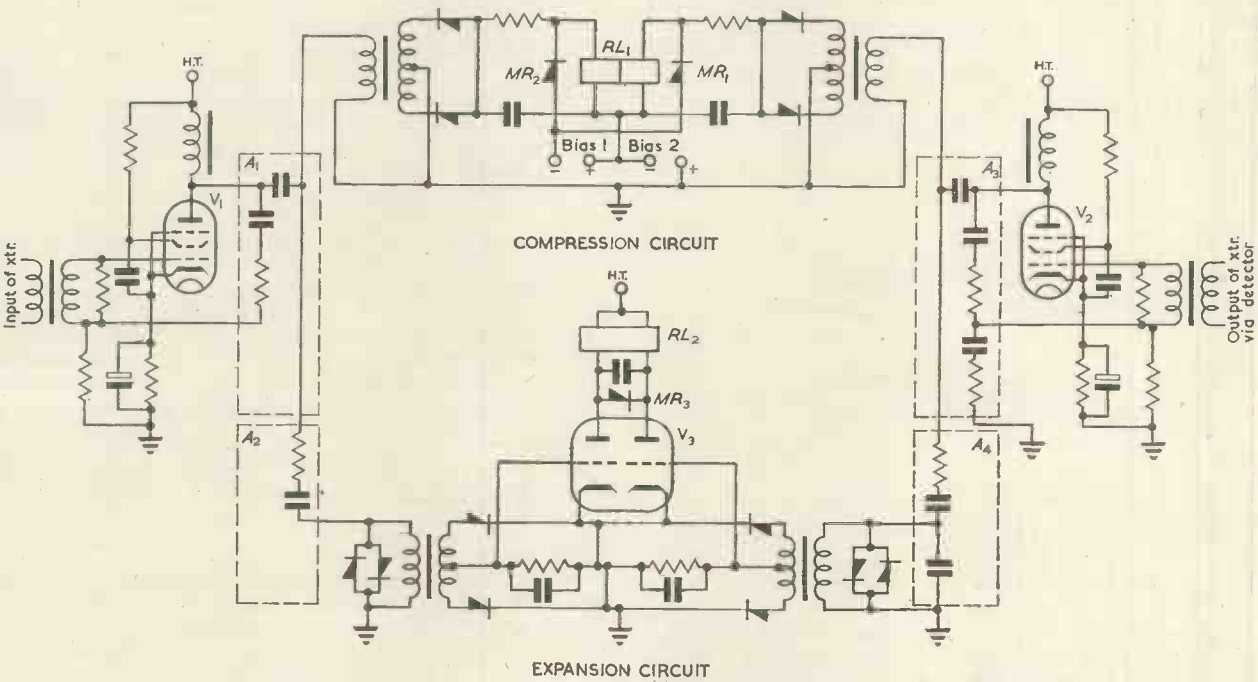


Fig. 7. Circuit of transmitter automatic monitor

shown in the lower part of Fig. 7. It is very simple indeed.

The programme signal passes through further networks which re-weight the characteristics as shown in Fig. 8. Again, and in conjunction with the detector used, this gives weighting of noise sensitivity to correspond roughly with audible assessment, particularly at low frequencies where there is the greatest likelihood of noise trouble on the transmitter. The weighting is, of course, represented by the difference shown between curves labelled "$A_1 + A_2$" and "$A_3 + A_4$."

The signals are then rectified in a conventional manner and used to supply negative bias to the two control grids of V_3, causing the anode circuits to be cut off. At very low input signals the value of grid bias to V_3 is such that anode current passes. Providing these currents are approximately equal in magnitude RL_2 will not operate. If, however, noise is present at the output of the transmitter (and not at its input) the left-hand section of V_3 will provide anode current during the gaps or low volume passages of the programme signal, but the right-hand section will remain cut off. This will cause RL_2 to operate.

MR_3 shunting the differential winding of RL_2 prohibits a failure in the left-hand half of the triode V_2 causing operation of RL_2. This gives this section of the monitor a side-stable action.

If either RL_1 or RL_2 operates, executive action is taken and the corresponding transmitter is withdrawn from service.

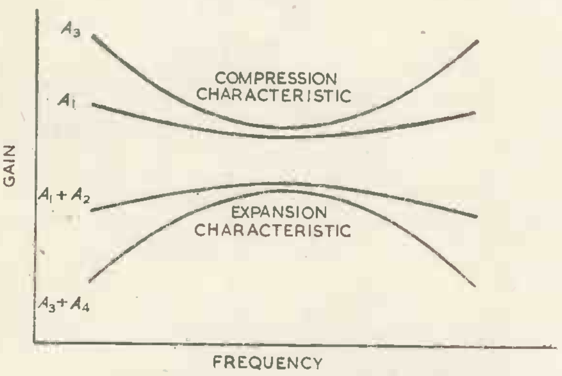


Fig. 8. Characteristics of weighting networks

It was mentioned earlier, that a number of transmitters are paralleled at their outputs. Obviously output separating networks must be employed between each transmitter and the communal aerial so that individual transmitter monitoring can take place.

This is not described here, as it is the subject of another article which is to follow[4].

There is, however, one general aspect which is of interest, namely the reliability and supervision of such automatic transmitters. Evidence so far secured from individual units and a field experiment with this objective in view, suggests that the reliability of modern equipment, designed for this purpose, is such that servicing visits need not be made more frequently than about once a month.

In spite of this, it is proper that a plan of this kind must be approached with caution.

In the initial period, therefore, several precautions may be taken, to be discarded later if operating experience shows them to be superfluous.

Obviously one such step is the retention of an employee in the vicinity of the transmitter so that he can pay daily visits to ensure that the equipment is working properly.

Nearly the same degree of supervision would be provided by a device which could send signals back to the parent station to disclose the state of the transmitters and some of the associated apparatus.

If there are three transmitter units supplied by one line through two alternative sets of programme input equipment, the essential information is:

(a) The number of transmitters still radiating programme signal.

(b) Whether the normal or the reserve programme input equipment, and perhaps drive equipment, is being used.

The latter information is of value as it discloses whether a reserve is available to deal with an apparatus fault. This information could be passed automatically over the phantom line circuit, but it would introduce complication which should be avoided if at all possible. Such complication is increased further in the case of stations operating in tandem.

A unit has therefore been designed which permits the above information to be secured by making a normal telephone call to the station. The exchange line is fitted with a special telephone which may be used by the visiting service engineer in the normal way. Connected to this telephone, is an auxiliary unit so that, in the absence of normal answering by a person at the station, a telephone call to that station is answered automatically, and coded information given as the reply.

The reply takes the form of groups of three "pips" of tone indicating that three transmitter units are radiating. If a transmitter unit has been switched off, its corresponding "pip" will be missing from the group, or if a changeover has occurred to the spare programme input equipment, a longer signal of a different pitch will be added.

This source continues to repeat the information for about two minutes, when it automatically clears the call.

Telephone calls to the station can be made as frequently as required, daily, weekly, etc., accordng to reliability factors, and the service team can arrange to visit stations according to their relative needs.

The telephone call need not be made from the parent station but from any public telephone, so that the service team, having visited one station can check up on others before proceeding on the next scheduled journey.

Acknowledgment

The authors are grateful to the Chief Engineer of the British Broadcasting Corporation for his permission to publish this work.

Erratum

We regret the caption to the photograph on the title page of Part 1 of this article was incorrect. This should have read "Automatic line monitoring equipment and telephonic indication panel at unattended stations."

REFERENCES

3. British Patent No. 15479/52.
4. Rendall, A. R. A., and Hunt, G. A. Transmitter Combining Circuits. To be published in *Electronic Engg.*

Local Authority Aids Exports

A prototype of the Ekco Airfield Radar Approach Aid has been ordered for evaluation purposes by the U.S. Air Navigation Development Board.

It is announced that Mr. Bernard Collins, manager of Southend Airport, will go with the equipment to the U.S. to demonstrate its capabilities throughout America. His journey is the result of a unique act of co-operation between a municipal authority and an industrial organization.

If this visit and demonstration are successful it will mean that the simple apparatus now working at this Municipal Airport will be ordered in appreciable numbers for use on airfields in the U.S.

The close collaboration between Southend County Borough Council and E.K. Cole Ltd., which has culminated in the request for Mr. Collins' services, is probably the first time a local authority has made a concrete commercial contribution towards securing work for its community and dollars for the country.

A Variable Voltage Stabilizer Employing a Cold-Cathode Triode

By F. S. Goulding*, B.Sc.

The advantages of cold-cathode over filament valves for low power applications are mentioned and a circuit arrangement is described in which a cold-cathode gas triode behaves as a D.C. *amplifier. This type of amplifier is shown to possess certain desirable characteristics when used as a voltage stabilizer in low current circuits. Applications of the circuit are then discussed.*

THIS article deals with a particular application of the low power cold-cathode triode valve. Although many circuit designers know of recent advances in the field of two-electrode voltage reference valves of the 85A1 type, it is not generally appreciated that considerable steps have also been taken in the design of stable trigger valves. It is hoped that this article will bring some of the advantages of such tubes to the notice of designers of electronic equipment.

As compared with hot-cathode valves, cold-cathode valves possess the following features which may be of importance in some cases:—

1. The life of a cold-cathode valve under low power conditions will certainly be much longer than that of a hot filament valve. Indeed, lives far in excess of 10 000 hours are common in some applications, and some tubes appear to improve with life when used at low power levels.

2. The elimination of power "waste" in the filament gives increased battery life in portable instruments.

3. The mechanical electrode structure of these valves is essentially simple and rigid. This results in increased robustness and reduced cost as compared with hot-cathode valves.

While comparison with transistors is pointless in this period of rapid development, it should be noted that cold-cathode gas-filled valves are relatively insensitive to temperature variations, while all semi-conducting devices are critically dependent on temperature.

In the type of tube referred to as a cold-cathode gas triode, the small discharge which occurs between grid and cathode when the voltage between these electrodes increases beyond the gas breakdown value, initiates a breakdown in the main anode-cathode space of the valve. Thus, a low power source may be used to switch a high power source into some suitable load. Typical cases of the use of valves in this manner are provided by various light-operated mechanisms. In these, the current through a photocell feeds the grid of a cold-cathode triode, causing it to strike at some predetermined level of illumination. The main discharge then switches a relay, the contacts of which perform the necessary switching of motors etc. Yet another example, involving much larger currents, is provided by the "ignitron" used in spot-welding equipment, as well as in radar modulators.

In all cases it will be noted that the cold-cathode valve has been regarded as a device for switching on power, rather than as a device possessing a power gain. This results naturally from the general picture of the operation of the device as an on-off switch. It is perhaps too obvious to point out that any on-off device can be used as an amplifier if the input signal can be made to control the frequency of switching. This, in fact, is the mode of operation of the circuit to be described. It is fortunate, for this particular application, that the valve envelope, while containing the basic performance essentials of an amplifier, also contains a reference voltage source in the form of the grid striking voltage of the tube. This combination of amplifier and a reference voltage source is ideal for use as a parallel voltage stabilizer.

Using the older types of cold-cathode valve, the output voltage obained from such a circuit is by no means constant, as the drift in the reference voltage supplied by the grid striking voltage is excessive. However, recent techniques of sputtering and the inclusion of a keep-alight electrode in the valve have improved the stability of grid striking voltage very considerably. In the older types of tubes, the grid striking voltage varied due to fluctuations in the residual ionization at the cathode. The effect of light on such tubes is well known. By maintaining a minute current in the keep-alight electrode, ionization is produced which swamps any residual effects and assists in stabilizing the grid striking voltage. An alternative method of producing this stabilizing effect, not employing a keep-alight electrode, is described later in this article.

Basic Operation of the Amplifier

The basic circuit is shown in Fig. 1. It employs a cold-cathode triode of a type chosen for the particular output voltage required. For detailed accounts of the operation of cold-cathode trigger valves, and typical circuits employing them, references 1-5 should be consulted.

In this circuit, the input voltage is applied to the control grid of a cold-cathode triode V_1 through a resistor R_1. A capacitor C_1 is connected from grid to earth and its value is made large enough to ensure firing of the main gap of the triode when the grid voltage exceeds its striking value (e_{st}). (The mechanism of firing in a trigger valve may be explained by assuming that a voltage e_{st} must be applied to the grid to initiate a grid-cathode glow discharge. On initiating this discharge the grid voltage drops by a definite amount (~30V). The charge produced in the grid-cathode space depends partly on this grid voltage swing and also on the value of the grid capacitor. As this charge is the cause of the main breakdown in the valve, it is found that a certain minimum value of C_1 is necessary for the valve to fire satisfactorily.) The H.T. voltage applied to the valve is less than that at which the anode-cathode space would break down due purely to the influence of anode potential, and the resistor R_2 is made large enough to ensure that the valve cannot remain in continuous conduction when it fires. Each time the valve conducts, it discharges C_2, the resistor R_3 limiting the current to a safe value, and, when C_2 is discharged,

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the current flowing through R_2 is insufficient to maintain the discharge within the valve. It therefore quenches, permitting C_2 to recharge through R_2 to a voltage e_{HT}. Capacitor C_3 is large compared with C_2 so as to average out the pulses of current through R_2.

Since the voltage applied to the anode of the triode is insufficient to produce conduction, it is clear that the meter M will register no current for input voltages lower than e_{st}. However, once e_{in} exceeds e_{st} by a small amount, the valve will fire and at least one pulse of charge will flow from C_2 through the valve. During the conducting period the valve behaves as a low impedance and, as in all gas discharges, the potential drop between any point in the gas space and the cathode of the discharge is practically fixed. In fact, on the valve firing, the anode-cathode voltage drops to a value of e_t (much less than e_{HT}) and the grid-cathode voltage drops to e_g (much less than e_{st}). On the discharge quenching, C_2 is left charged to a potential e_t, and C_1 to a potential e_g. Each capacitor then recharges through its appropriate resistor, C_1 towards e_{in} and C_2 towards e_{HT}. If the input voltage remains in excess of e_{st}, the valve will refire at the point where the voltage across C_1 reaches e_{st} and the whole process will repeat itself. The period between successive pulses of current through V_1 obviously depends on the values of R_1, C_1 and e_{in}.

This last statement is not absolutely correct, as the value of e_{st} is dependent on the anode voltage; it will only be

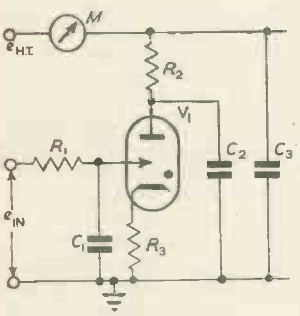


Fig. 1. Basic amplifier circuit

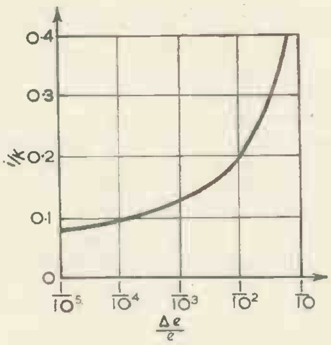


Fig. 2. Plot of i/k against Δe/e

correct if the time-constant R_2C_2 is short enough to permit the anode voltage to recover nearly to e_{HT} before the grid voltage rises to e_{st}. This implies that R_2C_2 is not much greater than R_1C_1. Initially, it will be assumed that this condition is satisfied and the way in which the results are affected when such is not the case will be discussed later.

On each occasion when valve V_1 fires, C_2 is discharged through a voltage $(e_{HT} - e_t)$. In recharging C_2, a quantity of charge equal to $C_2\ (e_{HT} - e_t)$ must flow through R_2 in order to fully recharge C_2. If the valve fires n times per second, a mean current equal to $nC_2\ (e_{HT} - e_{st})$ will be registered by the meter M. The frequency n being determined by the input voltage e_{in}, it is clear that the current through M is a continuous function of the input voltage for values of e_{in} in excess of e_{st}. The exact relationship between e_{in} and i is shown in Appendix 1 to be of the form:

$$i = \frac{C_2\,(e_{HT} - e_t)}{C_1R_1 \log_e \dfrac{(e_{in} - e_g)}{(e_{in} - e_{st})}} \qquad (1)$$

This may be simplified to:

$$i = \frac{K}{\log_e\,(e)/(\Delta_e)} \qquad (2)$$

where $K = C_2/C_1R_1\ (e_{HT} - e_t)$
$e = e_{in} - e_g$
and $\Delta_e = e_{in} - e_{st}$

For small values of Δ_e, that is when the input voltage exceeds the grid striking voltage by only a small amount, the period between pulses of current through the valve is long, and the anode voltage has fully recovered to e_{HT} before a pulse occurs. Therefore the relationship given in Equation (2) should hold.

Fig. 2 shows the current i calculated from Equation (2) for different values of $\Delta e/e$.

Using a new type of valve, the VX8086, circuit constants may be chosen thus: $C_1 = 680$pF, $R_1 = 3$MΩ, $C_2 = {\cdot}02\mu$F, $R_2 = 250$kΩ. The valve operating voltages are such that $e_{HT} - e_t = 70$V and $e_{st} - e_g = 30$V. It may be seen from these figures that K in equation (2) is approximately equal to 700μA. Since e in equation (2) is very nearly 30V, reference to Fig. 2 will show that a change of 0·3V in the grid voltage, above the striking point, will produce a mean current of approximately 150μA through the valve. Thus it may be seen that an effective "mutual conductance" of the order of 500μA/volt is realizable in the ideal case.

In practice this mutual conductance is not obtained due to small statistical variations in the value of the grid striking voltage e_{st}. One must remember that the growth of ionization in a cold-cathode valve is a statistical process and therefore the point to which the grid voltage requires to be raised, in order to cause a discharge in the valve, is indeterminate, varying with time, but only very occasionally departing far from the nominal value of grid striking voltage. These variations must not be confused with long term variations in the mean grid striking voltage, which are due to a cleaning up process slowly occurring in the valve. The rapid small fluctuations in the grid striking voltage only appear as minor variations in the mean current through the meter M, due to the averaging out effect of the various time-constants. However, they do cause a reduction in the effective mutual conductance of the arrangement, as the fluctuations in e_{st} mean that the value of $\Delta e/e$ in Fig. 2 is rapidly varying. In the VX8086 previously mentioned, the fluctuations in e_{st} are of the order of ± 0·25V about the mean value, and this results, in practice, in a mutual conductance of approximately 150μA/volt up to mean currents of roughly 150μA.

The effect of choosing time-constant C_2R_2 equal to or larger than C_1R_1 is difficult to estimate, owing to the complex way in which e_{st} depends on the anode voltage applied at the time of striking. If $C_2R_2 \gg C_1R_1$, then the anode voltage will not have recovered to e_{HT} when the grid voltage reaches the nominal e_{st}. This causes the frequency of oscillation to be lower than one would expect and equation (1) is rendered invalid, except possibly for very small values of Δe. For small values of Δe, it is possible that restriking takes place a long way along the tail of the C_1R_1 recovery and the anode voltage may well have recovered practically to e_{HT}. The results of equations (1) and (2) may then be expected to hold. As Δe increases, however, the current drops below the expected value (as calculated from equation (1) and a curve of the type shown in Fig. 3 results.

A more complicated mode of operation occurs when C_2R_2 exceeds C_1R_1 by a large amount. The frequency of operation is then determined purely by C_2R_2 and the valve becomes a true on-off switch, the current through M changing very little with increases in e_{in}, once e_{st} has been exceeded. The complete family of curves in Fig. 3 gives an idea of the type of characteristics to be expected as the time-constant C_2R_2 is varied by changing R_2.

Practical Details of the Amplifier

Experiments with this type of circuit have shown that the basic scheme of operation outlined provides a satisfactory explanation of the working of the circuit. A number of valve types have been used, but attention has

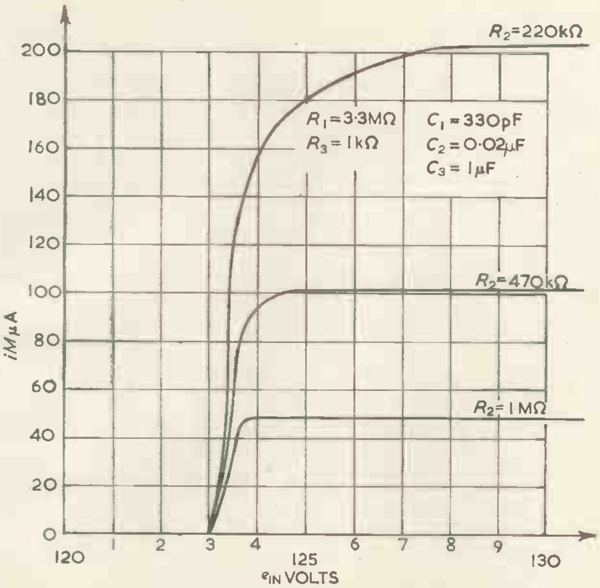


Fig. 3. VX8086 amplifier-typical characteristic

been concentrated principally on two types required for a particular application. Experience with other types of valve has shown that the same problems arise in operating all valve types and the results obtained may be applied to other valves chosen for particular special characteristics (e.g., high anode-breakdown voltage).

In all work carried out, it has been found that a small discharge within the valve is necessary to stabilize the grid striking voltage. In the VX8107, a valve designed to stabilize low voltage (≈400V) Geiger counter supplies, the small permanent discharge is provided by a keep-alight electrode which takes the form of a small cylindrical cathode surrounding the anode. A current of 2μA passed between this keep-alight cathode and the anode produces sufficient stray ions at the main cathode of the valve to ensure that the valve fires when e_{in} exceeds e_{st}. In the VX8086 type of valve (this valve was originally designed for use as a counting-rate valve in portable Geiger counter survey instruments) no keep-alight electrode is available and its function may be performed in a manner meriting further description.

Fig. 4 shows the actual circuit used and Fig. 3 gives measured characteristics for this circuit. It should immediately be noted that the auxiliary cathode of the valve V, together with its associated components *R* and *C*, performs the function of increasing the quenching current of the valve, thereby allowing the use of a small anode load (220kΩ). The more normal types of valve may not be used with anode loads smaller than 1MΩ. The point of interest here is the inclusion of rectifier W_1 and the additional 100MΩ resistor R_g in the grid circuit. With many samples of the valve this combination is not necessary, except for very small values of Δe, and the arrangement shown in Fig. 1 works satisfactorily. The stabilization of grid striking voltage in these cases appears to be achieved at each pulse by the few ions left from the previous pulse. This memory appears to last for several tens of milliseconds in most valves.

In some valves however, the ionization seems to disappear in a few milliseconds and, in consequence, large fluctuations occur in e_{st} depending on the ionization produced by stray light etc. To overcome this R_g and W_1 are inserted.

The operation of the whole circuit remains much as before except that each time V fires it discharges C_1 through W_1. When the discharge in the valve quenches, the grid rises relatively rapidly towards e_{HT} on a time-constant R_g (C_{strays} + C_{rect}) where C_{strays} = stray capacitance of grid, and C_{rect} = rectifier capacitance. The anode of the rectifier, on the other hand, rises on the time-constant R_1C_1 towards e_{in}, and, for small values of Δe, takes many milliseconds before reaching the nominal value of e_{st}. Long before this time, in fact a millisecond or so after the valve has quenched, the grid of V has risen above e_{st} and a small discharge has occurred from the grid to the cathode of the valve. Before the anode of the rectifier reaches e_{st} the grid is therefore passing a steady current (≈½μA) which is insufficient to strike the main discharge in the valve but is sufficient to stabilize the value of e_{st}. This results in a much improved performance of the circuit. The rectifier used is of the selenium miniature type (e.g. S.T.C. K3/3), the high reverse resistance of this type of rectifier being necessary in view of the 100MΩ resistor R_g Smaller values of R_g are not permissible as the steady current flowing in the grid would then cause the valve to fire due purely to the D.C. current flowing into the grid.

Operation as a Voltage Stabilizer

The use of a normal valve as a parallel voltage stabilizer is now quite common and it may be shown that, with such an arrangement, an output impedance equal to Z_o where

$$Z_o = 1/\beta g_m \quad .. (3)$$

and β = fraction of output voltage fed to grid

g_m = mutual conductance of valve

may be realized within the range of currents defined by the limiting conditions of valve operation. Also, it may be shown that a stabilizing factor η is obtained where

$$\eta = \frac{\text{Variation in output voltage}}{\text{Variation in input voltage}} = \frac{1}{\beta g_m R_L} \quad .... (4)$$

and R_L = stabilizer load.

These relationships are proved in Appendix II.

In this type of stabilizer, a portion of the output voltage is compared with a reference voltage and the difference between them controls the current through the parallel stabilizer valve in such a way that the output voltage is stabilized to a certain value. Adjustment of the actual stabilized voltage may be carried out by altering the proportion of the output voltage fed back to the stabilizer, or by changing the reference voltage.

It is clear, from the description of the amplifier in the previous sections, that a cold-cathode triode can be used as a parallel stabilizer within the limits of mean current the amplifier can pass. By virtue of the fact that the valve passes no current until the grid voltage exceeds e_{st}, the amplifier can be regarded as supplying its own reference voltage.

Two types of stabilizer have been constructed employing this principle. The first of these using the VX8107

Fig. 4. VX8086 amplifier with priming current

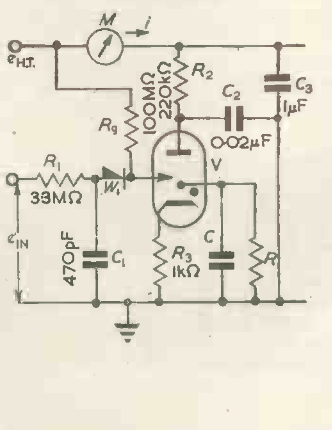
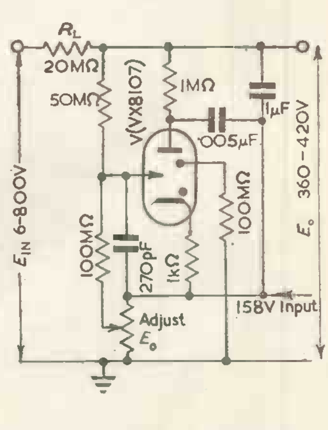


Fig. 5. Geiger counter voltage stabilizer



in the circuit shown in Fig. 5, is designed to control the voltage applied to a Geiger counter in a portable gamma survey meter. In this case, a variable voltage supply of 360 to 420 volts is required, while the load current may vary from zero to 3μA. Owing to the fact that a battery voltage of only 300 volts is available and that this supply voltage may fall to 230 volts, a cold-cathode triode relaxation oscillator together with a Cockcroft-Walton voltage multiplier is employed to develop an open circuit voltage of 600-800 volts to feed to the stabilizer valve. The voltage variation on the counter supply must not exceed 2 volts for the full range of input voltages and output currents.

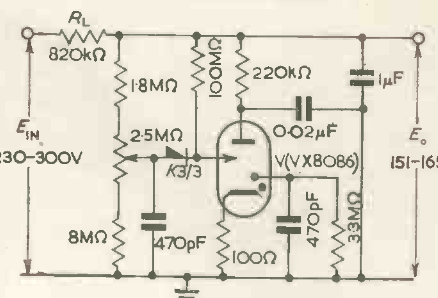
In the second application of this type of stabilizer the VX8086 is employed to stabilize a voltage of approximately 158 volts to supply anode voltage to another VX8086 used as a counting valve. Variation of the voltage over the range 151-165 volts is permitted, to allow adjustment for component and valve tolerances in the counting circuit. The maximum current taken by the load is 60μA and, over the range 0-80μA, the stabilizer maintains an approximately constant positive output resistance of 10kΩ. The circuit of this stabilizer is shown in Fig. 6.

In these circuits, the valves automatically adjust their mean current to such a value that the voltage drop across the series load resistors R_L is just sufficient to maintain the output voltage at a constant value. The actual output voltage is determined by the chains of resistors in the grid circuits and by the fact that, to a first approximation, the grid voltage must be e_{st} volts above the cathode potential. In the case of the VX8107 (Fig. 5), the cathode is returned to a point 158 volts above earth potential and variation in the output voltage is achieved by returning the grid chain of resistors to a variable voltage. The performance of each of these circuits has proved adequate for the application in view and the operation appears to be reliable on the valves tested up to now. With the VX8107 stabilizer shown in Fig. 5, the long time-constants used produce a small ripple on the stabilized voltage, particularly when the input voltage E_{in} is only just high enough to maintain E_o at its predetermined value. The ripple occurs at a frequency of a few cycles per second and its amplitude amounts to 2 volts or so.

The VX8086 stabilizer shown in Fig. 6 has been investigated with regard to its current-voltage characteristics and also with respect to the stability of output voltage with time. It appears that the greater part of the drift in voltage occurring with time may be accounted for by component rather than valve drifts, but even so, after suitable ageing in valve manufacture, and allowing a 5 minute switch-on period during which a change of up to 0·5 volts may occur, the drift over 500 hours, on samples measured, does not exceed $\pm$0·25 volts on the stabilized 158 volt line. A typical regulation characteristic is shown in Fig. 7, the mean current through the series load being plotted against the output voltage.

It may be noted that the small statistical fluctuations in the grid striking voltage, mentioned earlier, appear on the output as voltage fluctuations of the order of $\pm$0·1 volt. If necessary, these fluctuations can, of course, be reduced by increasing the value of the capacitor across the output.

Fig. 6. 158 volt stabilizer



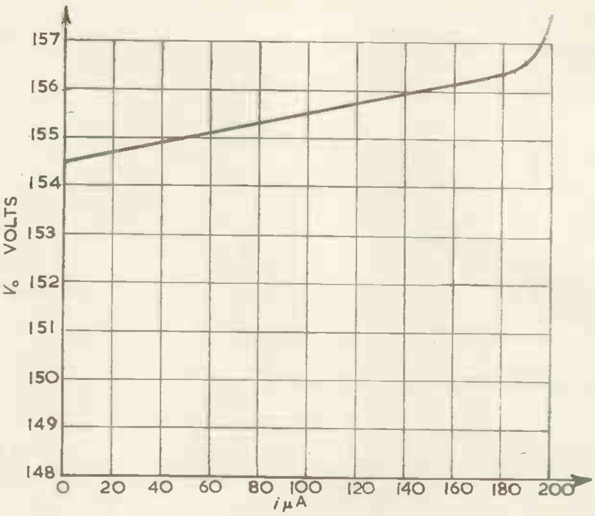


Fig. 7. VX8086 regulation characteristic

Comparison with two Electrode Voltage Stabilizers

The type of voltage stabilizer chosen for a particular application depends, of course, on the desired load current and input voltage variations. For applications where currents of the order of 1 to 30mA are required, quite adequate stabilization can generally be achieved by use of any of the standard range of voltage regulator tubes. For higher currents, or possibly where greater stability is required, a valve stabilizer employing a reference tube of the 85A1 type may be used. In the current region 200μA to 1mA a number of voltage regulator tubes have recently appeared with satisfactory characteristics. However, it is true to say that no good voltage regulator tube for use in the current region 0-200μA has appeared on the market. For higher voltages (above 500 volts) satisfactory corona regulators are now available for currents of 0-100μA, but the stability of these tubes appears to be relatively poor at present.

The difficulties of constructing a normal voltage regulator tube to operate in this current region are obvious. Any normal 2 electrode discharge tube exhibits a negative resistance characteristic below 100μA and, unless care is taken in the external circuit design, oscillations result. Also, as the discharge is very small, the cathode glow may not completely fill the cathode and the voltage depends upon the portion of the cathode on which the glow occurs. This results in a wide spread in characteristics from valve to valve in this current region. The value of the negative resistance is indeterminate and great difficulty is experienced in compensating for any negative resistance which may occur. To overcome some of these problems a priming electrode, passing a small current to the cathode, has been employed. This tends to flatten the rise in voltage at low currents, but the effectiveness of priming current appears to vary a great deal from valve to valve and a large spread in voltage results. Also with any particular valve, the operation is critically dependent on the priming current and it is virtually necessary to stabilize this current in order to achieve a constant voltage output.

The circuit shown in Fig. 6 overcomes these problems. Its practically constant low output impedance is a great improvement on the rather variable negative and positive resistance characteristics of the more conventional regulator tubes in this current region. Also, the facility of easy adjustment of voltage over a small range avoids any difficulties due to the variations in voltage from valve to valve, and the ability of the circuit to maintain its performance down to currents of a few micro-amperes assists in reducing wastage in power taken from batteries.

For higher voltages, corona regulator tubes may be used, but it should be pointed out that the VX8107 (Fig. 5), or a similar stabilizer, possesses a potential advantage over a corona regulator, in that the output voltage may be varied over a small range while maintaining a low output impedance. Such variation of voltage using a corona regulator may only be achieved by rather crude mechanical bellows or by returning the cathode of the regulator to a potentiometer across a stabilized low voltage. Using the second method, an impedance must be introduced effectively in the output circuit, the value of this impedance depending purely on the power one is willing to waste in the potentiometer. In the triode type of stabilizer described earlier, only a very small amount of power need be wasted to achieve a voltage variation.

It should further be noted that the development of new cold-cathode triode tubes having high quenching currents, or high anode-breakdown voltages, may allow this form of stabilizer to be used in higher voltage and possibly higher current regions.

Acknowledgments

The author is indebted to the Director, Atomic Energy Research Establishment, for permission to publish this article. He also expresses his thanks to Mr. C. H. Tosswill, of Mullard Ltd., for assistance given in this work.

Appendix I.

If in the circuit shown in Fig. 1:—

e_{st} = grid striking voltage

e_g = grid-cathode voltage drop when tube is conducting

e_{HT} = voltage applied to anode of valve

e_t = anode-cathode voltage drop when tube is conducting

and if one assumes that the anode voltage fully recovers to e_{HT} between successive cycles, then:—

Charge flowing out of C_2 per cycle $= C_2\ (e_{HT} - e_t)$ and mean current through M $= n \cdot C_2 \cdot (e_{HT} - e_t)$ where n = frequency of oscillation.

Now the grid waveform is as shown in Fig. 8.

The rise takes the form:—

grid voltage $= e_g + (e_{in} - e_g)\ (1 - e^{-t/C_1R_1})$

The period T is therefore determined by:—

$e_{st} = e_g + (e_{in} - e_g)\ (1 - e^{-T/C_1R_1})$

Re-arranging this:—

$$T = C_1R_1 \log_e \frac{(e_{in} - e_g)}{(e_{in} - e_{st})}$$

$$\text{Mean current through } M = \frac{n\,C_2\ (e_{HT} - e_t)}{C_1R_1 \log_e \dfrac{(e_{in} - e_g)}{(e_{in} - e_{st})}} \quad \ldots\ldots (1)$$

Appendix II

Fig. 9 shows the type of voltage stabilizer referred to in this paper as a parallel stabilizer. As shown in this figure, a conventional type of hot-cathode valve is used and a battery provides the reference voltage.

The output impedance and stabilizing factor of this circuit are easily determined as follows:—

Suppose a change of $+\Delta E$ is superimposed on the output lead.

Then:

voltage change on the grid of V

$$= \frac{R_1 \Delta E}{R_1 + R_2}$$

and, if g_m = mutual conductance of V, and we assume that the anode impedance is very high:—

$$\text{Current increase through V} = \frac{R_1}{R_1 + R_2} \cdot \Delta E \cdot g_m = I$$

It may therefore be seen that, to the source of voltage imposing the change E on the output lead, the circuit appears to have an output impedance Z_o where:—

$$Z_o = \frac{\Delta E}{I} = \frac{R_1 + R_2}{R_1 g_m}$$

$$\text{Now} \quad \frac{R_1}{R_1 + R_2}$$

= fraction of output voltage fed back to the input $= \beta$

$$\therefore Z_o = 1/\beta g_m \quad \ldots\ldots\ldots\ldots (3)$$

Since the same reasoning applies to voltage changes on the output due either to changes in load or changes in input voltage, it may be seen that:—

$$\text{Stabilizing Factor } \eta = \frac{\text{Change in output voltage}}{\text{Change in input voltage}} = \frac{Z_o}{Z_o + R_L}$$

Since $R_L \gg Z_o$,

$$\eta \approx Z_o/R_L = \frac{1}{\beta\, g_m\, R_L} \quad \ldots\ldots\ldots\ldots (4)$$

If one assumes that, for the valve to pass any current,

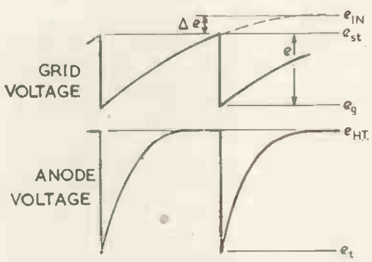


Fig. 8. Waveforms for Fig. 1

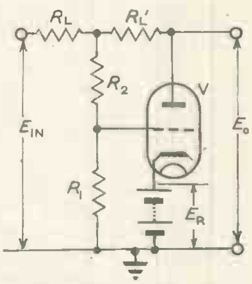


Fig. 9. Conventional parallel stabilizer[4]

the grid of V must be nearly at its cathode potential, the output voltage can be seen to be equal to E_R/β to a first approximation. Also it may be noted that the inclusion of the resistor R_L (shown dotted in the diagram) may, if the resistor value is chosen correctly, allow complete compensation of output voltage for a limited range of input voltage changes. In our case, however, the consequent increase in output impedance is undesirable and this mode of operation has not been considered.

In adapting this circuit to the use of a cold-cathode triode, all that is necessary is to use the amplifier of Fig. 1 to replace the valve V. The resulting circuit behaves in an exactly analogous way except that the cold-cathode valve passes no current until its grid voltage exceeds e_{st}. Thus the output voltage is $(E_R + e_{st})/\beta$, or, if E_R is removed, e_{st} may be used as the reference voltage, in which case, the output voltage is e_{st}/β. The remaining characteristics of the stabilizer can be predicted from equation (3) and (4) by using the relevant measured constants.

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A Gramophone Pick-up Pre-Amplifier

By E. J. Miller, B.Sc.

A HIGH quality power amplifier was described in a previous issue[1]. This amplifier can be used for gramophone reproduction, but the low output signal obtained from a pick-up necessitates the use of a pre-amplifier. Some frequency compensation is also necessary and this can, conveniently, be included in the pre-amplifier.

When designing a gramophone pick-up pre-amplifier it is difficult to decide which frequency characteristic controls are really necessary and, indeed, desirable. The pre-amplifier about to be described represents one opinion only of those controls which must be provided, and yet be consistent with the need for simplicity.

In recording, it is usual to attenuate the bass end of the frequency range and sometimes emphasize the treble end. The amount of this attenuation and emphasis is clearly stated and defined by the major recording companies, thus, the only correct method of replaying is to apply a frequency characteristic which is the inverse of that applied in the recording process. Of course, this ideal pre-supposes that the pick-up and the loudspeaker, in the usual reproducing chain, have flat frequency characteristics. In practice, the limiting factor is invariably the loudspeaker. Where the loudspeaker and pick-up depart from the ideal, the departure is so abrupt that any attempt to electrically compensate is worse than useless.

The usual reproducing chain, referred to above, consists of a pick-up, an equalizer, a power amplifier and a loudspeaker. The best possible practice is that, with the exception of the equalizer, each of these components should have a flat frequency response and the equalizer should apply exactly the inverse frequency characteristic to that applied by the record manufacturer. The shortcomings of the equipment should not be mulled by the discreet adjustments of the owner.

Unfortunately, as always, concessions must be made, but it is as well to keep the ideal in mind. With modern equipment few concessions are necessary. The main two are surface noise and turntable rumble. The turntable rumble being accentuated by the pick-up arm resonance. Usually the loudspeaker makes an effective bass filter for this low frequency rumble. If the loudspeaker is of such quality that it does not, then it is worthwhile seeking the real solution which lies in curing the rumble at its source. Surface noise, again, has its solution in using a pick-up with its upper resonance well above the audible range and by playing disks having an inherently low surface noise.

In the pre-amplifier about to be described three replay characteristics are incorporated. These are the inverse of those applied by:

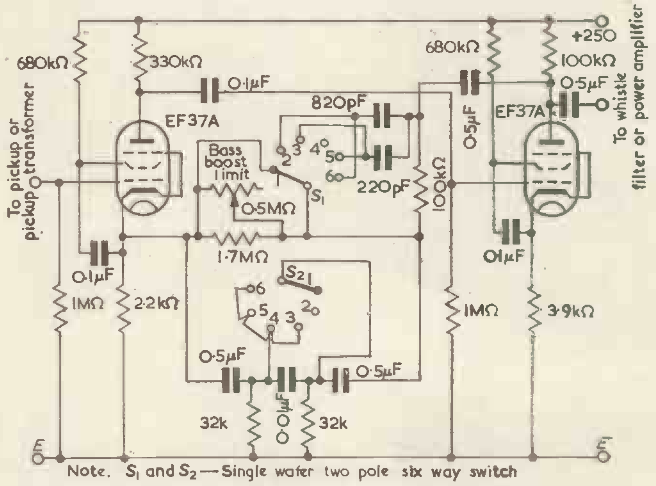
(a) Many American companies (including records by British companies originating in America)—the N.A.B. characteristic.

(b) the E.M.I. group of companies.

(c) The Decca group of companies.

Now the N.A.B. characteristic employs strong pre-emphasis of the high frequency range. Thus in replay, for correct reproduction, considerable high frequency attenuation must be applied and surface noise is not troublesome. This does not apply to E.M.I. records, and while the correct characteristic is provided for good records the same characteristic is, alternatively, provided with two conditions of high frequency attenuation, to make worn records tolerable. The Decca characteristic has a measure of pre-emphasis but additional high frequency attenuation can be obtained by using the final E.M.I. condition since the Decca and E.M.I. bass characteristics are similar.

Possibly, some explanation of the choice of characteristics is desirable. The N.A.B. characteristic (a) is the



Note. S_1 and S_2—Single wafer two pole six way switch
Switch Positions 1—Radio 2—N.A.B. 3—Decca 4—E.M.I. 5—E.M.I. (with top cut 1) 6—E.M.I. (with top cut 2)

Fig. 1. The complete pre-amplifier

characteristic adopted as standard by the National Association of Broadcasters of America[2]. This association introduced the standard in 1941 and most American recording companies and broadcasting stations now conform. It also represents a general characteristic suitable for records of indifferent quality. Characteristics (b) and (c) provide for almost all records originating in Britain as most record companies are subsidiaries of one of these parent companies.

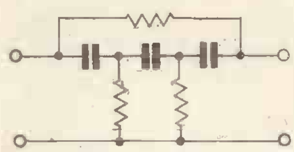


Fig. 2. Basic bass correction network

The pre-amplifier circuit is shown in Fig. 1. Equalization is achieved by frequency dependent feedback networks between the anode of the second valve and the cathode of the first. The basic circuit for providing the rise at the lower end of the frequency range is the network shown in Fig. 2. This is an alternative configuration to the well-known bridged-T equalizer, but has the advantage of economy in capacitor sizes at low frequencies[1]. It was designed to give infinite rejection at 10c/s; however, the amount of rejection can be controlled by the shunt resist-

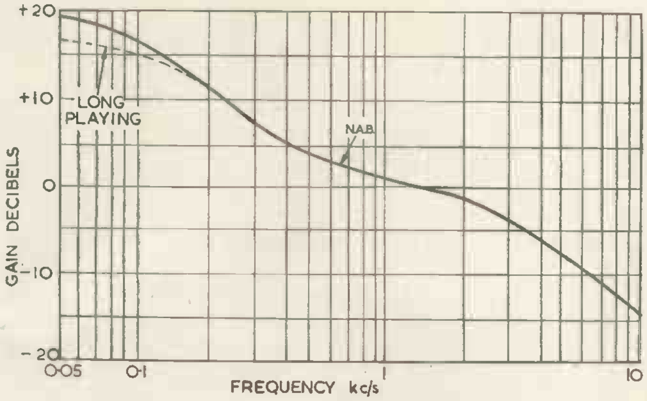


Fig. 3. Pick-up pre-amplifier, gain-frequency response N.A.B. condition, arbitrary zero

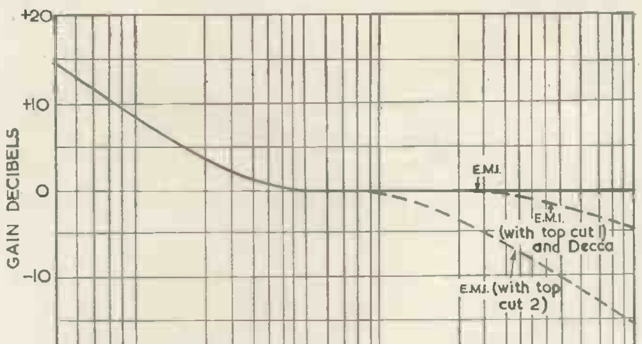
ance without materially altering the shape of the characteristic as far as the rejection limit. High frequency attenuation is obtained by shunting the feedback controlling resistor with a capacitor.

It will be seen that the pre-amplifier is fitted with a bass boost limit control. It should be possible to set this control to its maximum value of resistance and leave it there, if this is so, the control and its shunting resistance, could well be omitted and replaced by a 390kΩ resistor. However, if the control proves to be necessary it should be used sparingly. Its effect, at an intermediate setting, is to limit the bass rise and then maintain a constant gain at the low frequencies. When the resistance is fully removed there is no bass rise whatever.

Further facilities could, of course, have been provided. If these are desired, sufficient data can be derived from the frequency characteristics to satisfy most requirements. One facility which may perhaps be desired is an L.P. replay characteristic. This characteristic deviates from the N.A.B. characteristic by about 4db below 100c/s and can be obtained by changing the 390kΩ resistor, referred to above, to one of 330kΩ[2]. Its necessity is doubtful. For the majority of equipment, the N.A.B. characteristic will suffice.

The frequency response curves obtained from the pre-amplifier are shown in Figs. 3 and 4. The overall voltage gain at 1 000c/s when terminated in 220kΩ is 36db with the charcteristic switch set to N.A.B. Other settings of this switch are not materially different. Thus an input of −29db relative to 1 volt, 35mV peak is required to fully load an amplifier such as the one described earlier[1]. This requirement is met by most high impedance pick-ups, but for some low impedance pick-ups an input transformer will be required.

Fig. 4. Pick-up pre-amplifier, gain-frequency response, arbitrary zero



Crystal pick-ups are not suitable for use with this pre-amplifier since they are fundamentally constant amplitude devices and require little bass compensation. However, their use is to be deprecated since the falling high frequency response is usually compensated, in the pick-up, by a mechanical resonance which contributes a very high rate of attenuation above that resonance.

For radio reproduction no frequency compensation is required, however, the 9kc/s note which can be heard on some programmes may be troublesome. This can be removed with the aid of a rejection filter described in the Appendix. Use of such a rejection filter with its introduction of sharp attenuation in the amplifier frequency response, is deprecated by some authorities. Thus its use or not is the responsibility of the individual, but in any case it should be removed for gramophone production.

Appendix

9kc/s Rejection Filter

A suitable filter for removing the 9kc/s note, produced by the carrier beat of two radio stations, is the bridged-T. The particular configuration shown in Fig. 5 is most convenient since the rejection frequency can be controlled by a single variable capacitor. Variation of the parallel resistance arm controls the degree of rejection.

The filter can be included between the pre-amplifier and the power amplifier.

The inductor consists of 2 000 turns, centre tapped, of

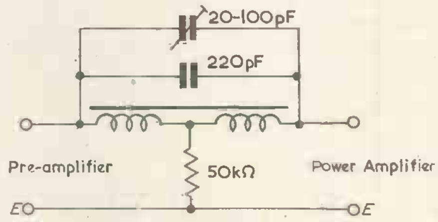


Fig. 5. 9kc/s rejection filter

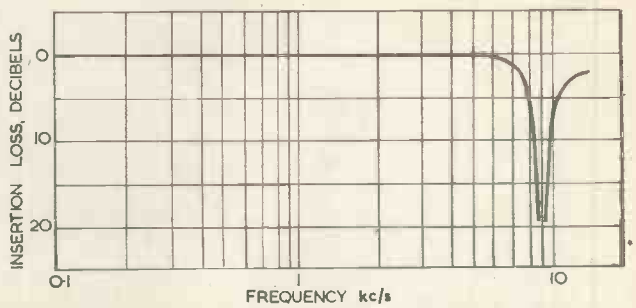


Fig. 6. 9kc/s rejection filter. Insertion loss between low impedance source and a 250kΩ termination, arbitrary zero

38 S.W.G. enamel and single cupronomium wire wound on a bobbin having 1 1/16in. square cheeks and width between cheeks of ¾in. The core is ⅜in. square Stalloy, 15 mil. laminations No. 158 made by Magnetic & Electrical Alloys Ltd. Inductance 1·1H.

Acknowledgment

The author is indebted to Mr. F. A. Milne for help and advice received.

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An Electronic High Voltage Insulation Tester

By L. R. Hulls*, B.Sc., A.Inst.P., and K. A. Mackenzie*, A.M.I.E.E., A.M.Brit. I.R.E.

THIS instrument has been designed to meet the need for a reliable, simple and portable equipment for determining the performance of insulating material under high voltage stress. The apparatus gives an output voltage continuously variable from 500-10 000 volts D.C., together with a means for measuring resistance values up to 250 000 megohms and an aural indication of the A.C. component of leakage or ionization current through the test specimen. The tester is designed around the now familiar R.F. type power supply which generates the test potential (see Fig. 1). A valve voltmeter circuit is used to measure current and voltage and a small two valve amplifier detects the presence of ionization. A conventional type power supply permits operation of the instrument from the 50c/s mains.

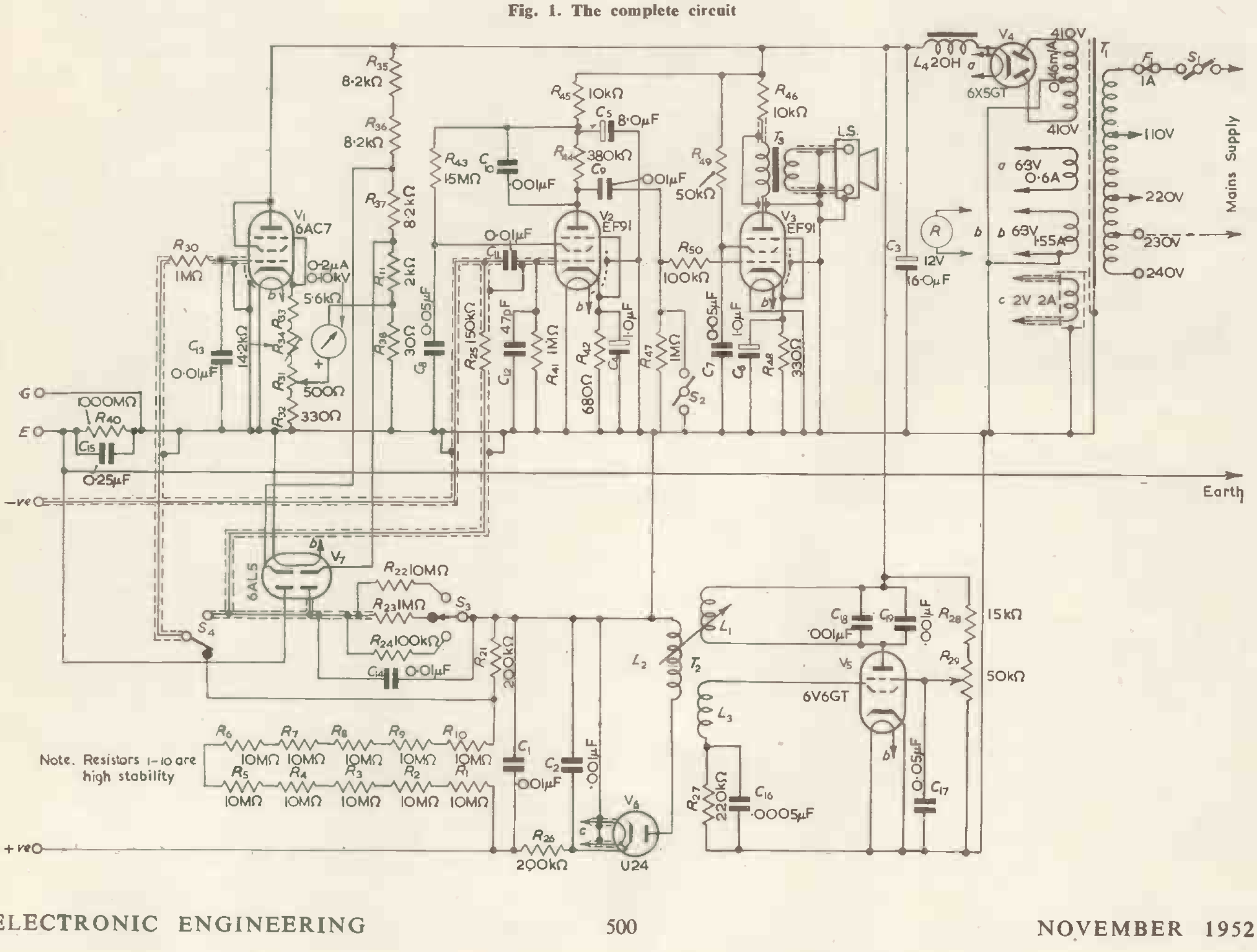
High Voltage Power Supply

A number of articles on the design of these units have already been published[1,2]. Most of this work, however, is concerned with the design of fixed voltage supplies which are simpler than the variable supply required in this case.

* The English Electric Co. Ltd.

Owing to the variable oscillator output it is not possible to supply the E.H.T. rectifier filament from the oscillator, and a separate 50c/s winding on the mains transformer is necessary. A single valve rectifier is used since voltage doubler circuits are difficult to operate under this condition owing to the self capacitance between the individual rectifier heater windings on the mains transformer. Efficient operation of the supply is largely dependent upon proper design of the coil. It is essential to keep the Q of the various windings as high as possible. For this reason litz wire has been used for the anode coil, but for the high voltage coil there appears to be little advantage in using multi-strand wire. The condition for maximum voltage step-up is critical coupling, K_c, between the tuned primary and secondary coils. Critical coupling, however, gives very poor regulation and the coupling for practicable purposes should be approximately $5K_c$. The secondary circuit is tuned by its own self capacitance and in order to avoid appreciable changes in frequency due to the double peak nature of the resonance curve of the coupled circuits, it is usual to obtain the grid excitation by coupling to the secondary coil rather than to the anode tank circuit. This

Fig. 1. The complete circuit



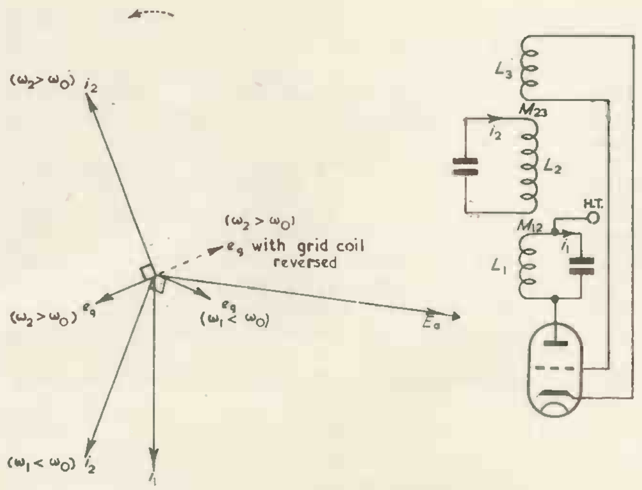


Fig. 2. The two conditions for oscillation

form of coupling allows two stable oscillation frequencies depending upon the polarity of the grid coil. The lower frequency is used as this gives the best result with a higher effective tank circuit Q. The vector diagram Fig. 2 illustrates the two conditions for oscillation. If i_1 and i_2 are the respective currents in primary and secondary circuits and M_{12} and M_{23} are the mutual inductances coupling primary to secondary, and secondary to grid coil, then the voltage e_g induced in the grid coil is in quadrature with i_2 and is given by the relation

$$e_g = j\omega M_{23} i_2$$

If the two circuits are tuned to the same resonant frequency of w_0 then normal coupled circuit theory gives two resonant peaks at frequencies ω_1 and ω_2 where:

$$\omega_1 < \omega_0 \text{ and } \omega_2 > \omega_0$$

The voltage induced in the secondary E_s is given by:

$$E_s = j\omega M_{12} i_1$$

now:

$$i_2 = \frac{j\omega M_{12} i_1}{R_2 + jX_2}$$

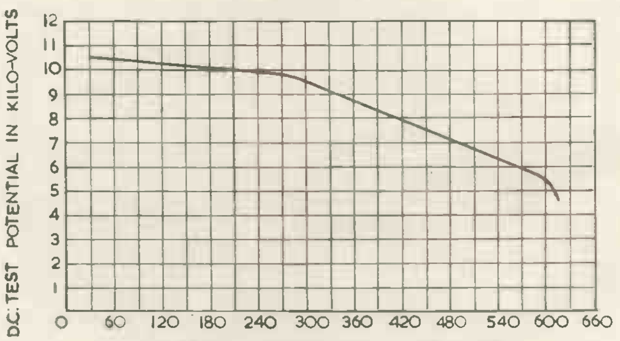
Where R_2 and X_2 are the secondary resistance and reactance.

Therefore:

$$i_1 / i_2 = \frac{\omega M_{12}(jR_2 + X_2)}{R_2^2 + X_2^2}$$

Since X_2 is negative for $\omega_1 < \omega_0$ and positive for $\omega_2 > \omega_0$, and X_2 is large compared with R_2, i_2 is either almost in phase with i_1 or almost 180° out of phase with i_1 according to whether the frequency is ω_1 or ω_2. The tank voltage leads i_1 by some angle less than 90°. The necessary condition for oscillation is that the grid voltage shall have a component in phase with the anode voltage E_a. The

Fig. 3. Regulation



vector diagram Fig. 2 illustrates that this condition is achieved in the case of oscillation at ω_1 and is not achieved in the case of ω_2 unless the vector e_g is turned through 180° by reversing the grid coil.

A smooth adjustment of output voltage is achieved by a potentiometer controlling the screen potential of the oscillator valve, this provides a means of controlling the output voltage without very much change in the output impedance. The secondary load resistance is normally very high and the loaded Q of the tank circuit is not reduced below a critical value for stable oscillation. It is possible, however, to encourage spurious oscillation under conditions of excessively low load, such as encountered when charging a large capacitance from the output. The frequency of 100kc/s makes possible efficient smoothing with relatively small capacitors, of the order of 0·001μF, and the equipment is therefore non-lethal unless the output is being used to charge a large capacitance. The total rectified output required is 10kV D.C. at 300μA, i.e. 3 watts for a D.C. input of 10 watts, giving an overall efficiency of 30 per cent at full load (neglecting filament consumption). A valve of the 6V6 type is therefore suitable for an oscillator, while the Mazda U24 provides a robust corona free 10kV rectifier. At 10kV it is not necessary to use corona shields as long as reasonable care is taken to avoid sharp bends and edges at the high potential points. The E.H.T. transformer is wound on S.R.B.P. tube and dipped in pure

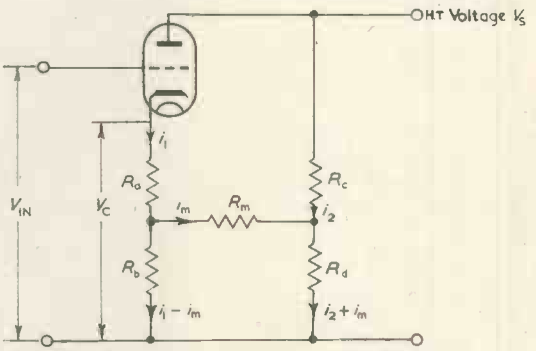


Fig. 4. Basic circuit of the valve-voltmeter

hydro-carbon wax. The losses in the coil former do not produce any appreciable drop in the anode circuit Q but the brass screening-can reduces the D.C. output by 10 to 15 per cent. It is not advisable to include the oscillator valve inside the can because any increase in coil temperature reduces the Q of the coil with consequent falling off in output. The regulation of this type of supply is shown in Fig. 3. Provided the coil assembly is correctly adjusted the curve over the working range is reasonably flat. In production adjustment may be achieved by varying the anode coil coupling.

Valve Voltmeter

The problem of determining high values of insulation resistance, up to 250 000MΩ, requires the measurement of very small currents, less than 0·05μA. This is achieved by a high impedance valve voltmeter which measures the voltage drop across any one of three resistors placed in series with the load. In the circuit chosen a high slope pentode strapped as a triode is used in a bridge circuit, Fig. 4. The bridge is balanced by the potentiometer R_{31} to give zero deflexion on the meter M_1 for zero input. The resistor R_{34} is adjusted so that an input of 20V D.C. gives full scale deflexion of the 1mA, 100Ω meter movement.

An important requirement of the valve voltmeter is that the reading shall not be affected by changes in H.T. potential due to mains supply variations. The basic circuit is shown in Fig. 4. Analysis of this circuit gives the following expression for the meter current i_m in terms of

F

the cathode voltage, V_c, H.T. voltage V_s and the circuit resistors R_a, R_b, R_m, R_c and R_d.

$$i_m = \frac{\dfrac{R_b V_c}{R_a + R_b} - \dfrac{V_s R_d}{R_c + R_d}}{R_m + R_d + R_b - \dfrac{R_d^2}{R_c + R_d} - \dfrac{R_b^2}{R_a + R_b}}$$

We may simplify this expression to:

$$V_c = K_1 V_s + K_2 i_m$$

where K_1 and K_2 are constants. The value of i_m is determined by the value of V_c, and if for a given value of V_c the current is to be constant and independent of H.T. voltage then V_c must vary with H.T. in accordance with the above equation. If the cathode potential is small compared with V_s then the valve current i_a is given by the following equation, assuming linear valve parameters.

$$i_a = V_s / R_p + g_m V_g$$

Where R_p is the anode resistance
g_m the mutual conductance
and V_g the grid cathode voltage.

Analysis gives the following expression for V_c in terms of i_a where K_3 and K_4 are constants determined by the circuit resistances:

$$V_c = i_a K_3 + V_s K_4$$
$$= K_3 V_s / R_p + K_3 g_m V_g + V_s K_4$$

Now,

$$V_g = V_{in} - V_c$$

$$\therefore V_c = \frac{V_s}{1 + K_3 g_m}(K_3 / R_p + K_4) + V_{in} \frac{K_3 g_m}{1 + K_3 g_m}$$

We may simplify this expression to

$$V_c = K_5 V_s + K_6 V_{in}$$

where K_5 and K_6 are constants.

By proper choice of component values it is possible to make

$$K_5 = K_1$$

Then the two equations for V_c can be solved to give the following linear relationship between i_m and V_{in}:

$$K_6 V_{in} = K_2 i_m$$

which is independent of V_s.

In practice a 20 per cent change in mains voltage gives a 1·5 per cent change in meter reading, this being due mainly to heater variation.

Determination of Insulation Resistance

Insulation resistance is obtained by measuring the current through the specimen at a known value of applied potential. The valve voltmeter is first switched to a potential divider across the E.H.T. supply to measure the test voltage, and then across any one of three resistors, corresponding to the three current ranges, placed in series with the specimen under test, to measure the current flowing. The sensitivity limit is reached when the current to be measured becomes comparable with the gas current flow in the grid circuit of the valve voltmeter. The meter has two scales, one calibrated directly from 0 to 10kV, and the other from 0 to 2μA with a multiplier switch for $\times 10$ and $\times 100$.

Indication of Ionization

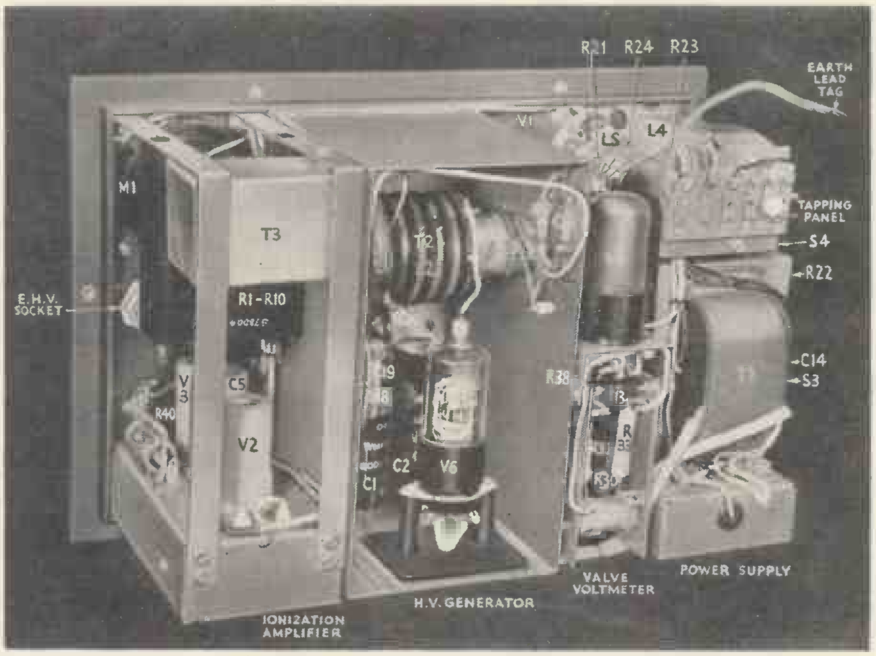
When a high potential is applied to an insulating material it causes ionization of the gas in any voids existing in the material, producing discrete break-downs which cause a fluctuating component superimposed on the steady leakage current. These fluctuations produce a voltage drop across the impedance $R_{25}C_{11}$, which is amplified some 40,000 times and fed to a loudspeaker. There is a definite threshold at which ionization commences, and the gain of the amplifier has been made just sufficient to detect the onset of ionization. The frequency characteristic of the ionization signal is such that the output from the amplifier is proportional to bandwidth and there is, therefore, no advantage in extending the low frequency response below 100c/s. The amplifier used is 35db down at 50c/s and 12db down at 10kc/s.

Ionization produces a frying noise from the loudspeaker which increases in intensity as the applied potential is increased until ultimately the material breaks down completely. Although the gain of the amplifier is sufficient to detect the onset of ionization, sufficient work has not yet been carried out to enable a safe level of ionization to be specified. However, the incorporation of the ionization amplifier does permit useful comparison tests to be made.

Special Features Occurring in High Voltage Measuring Technique

Since resistance values as high as 250 000MΩ are to be measured with or without an earth on one side of the load, special precautions must be taken to ensure that the accuracy of the instrument is not impaired by unwanted leakage paths. In practice, it is not possible to keep the stray leakage path resistances large compared with 250 000MΩ, and it is necessary to arrange that all leakage currents are by-passed to the power-pack side of the current measuring resistors. It is also necessary to make sure that any leakage resistance appearing across the current measuring resistors is large compared with 10MΩ which is the highest range resistor used.

To meet these requirements, a novel construction has been employed in this instrument. The chassis and all components are mounted on the insulated front panel which has a special creep barrier to increase the length of the leakage path to the case, which is normally at earth potential. The chassis and internal metal-work are arranged as a guard system and connected to the power pack side of the current measuring resistors so that any leakage to them is not registered on the meter. This is especially significant when we consider the E.H.T. rectifier filament winding on the mains transformer, since any leakage to the primary winding will appear directly across the test specimen when one side of the latter is earthy. By using mica-



A rear view of the complete instrument removed from its case tape insulation and by careful guarding of the windings, the effect of leakage current may be reduced to negligible proportions. Although varnish or wax impregnation has proved adequate, better results may be obtained if P.V.C. impregnation is used. It is also necessary to guard the E.H.T. output socket and high voltage resistance block, and for the latter a polythene sprayed metal screen has been employed. Leakage paths from the test specimen itself must be considered and, to enable the user to eliminate unwanted surface leakage paths on the test specimen, the guard system has been brought out to a terminal on the front panel.

Protection Circuits

In order to protect the meter and standard range resistors a biased diode V_7 is arranged to limit the potential drop across these components to 25V, i.e. 25 per cent in excess of F.S.D. This diode also limits the error in voltage reading, since the voltage drop across the current resistors is always small enough to be ignored in comparison with the output voltage. The other half of the diode V_7 protects the insulation of the tester between case and guard in the event of a breakdown to earth on the test specimen, it also prevents excessive voltage stress in the instrument if breakdown occurs while flash testing components, in which case the negative test lead should be strapped to the earth terminal.

Conclusion

In conclusion, this instrument has proved itself extremely useful in laboratory and factory measurements on all types of equipment from small components and samples to large machines and switchgear, and promises to give an improved method of measuring insulation resistance.

Acknowledgments

The authors would like to thank Mr. E. Cattanes for his general guidance on the design and Mr. A. Bailey for his assistance in the circuit development. The paper is published by the kind permission of the English Electric Company Limited.

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A NEW AIRPORT CONTROL TOWER

The decision to construct a new control tower at Luton Municipal Airport was an outcome of the necessity to keep abreast of air traffic control requirements which have resulted from the development of modern aircraft.

The new tower is four storeys high, has an overall height to roof level of 52ft 6in., the height of the control room above ground level being 42ft.

The ground floor will be used as a reception room where pilots will report their arrival or destination. It is intended that the first floor will be developed in the future as a meteorological office, while the second will be used as a records office and teleprinter room.

On the third floor is an equipment room where the main V.H.F. R.T. equipment is housed. Also in this room is a standby battery plant which comes into operation automatically should there be any failure in the general main supply of power to the control tower.

In the control room, at the top, there is transmitting and receiving equipment for V.H.F. R.T. as well as a Marconi AD.200 V.H.F. D.F. apparatus, together with telephones, crash alarms, wind speed and direction indicators, all of which equipment has been built into the Control Officer's desk which faces directly on to the airfield.

All telephone, electric light and other cables are concealed in a duct running from the switch gear room on the ground floor to the various offices in the building.

The wireless aerials for the V.H.F. R.T. communication and the equipment for the wind-speed and direction indicators have been erected on the roof of the tower. Both services are erected on a steel mast, the aerial leads, together with wind-speed and direction cables passing through the centre of the mast into the duct provided on the control room floor and equipment room.

The general appearance of the tower and the layout of the control room are shown in the accompanying photographs.

A Feedback-Pair Video Amplifier

By V. H. Attree*, B.Sc.

The general design of low-pass wideband amplifiers is discussed and it is shown how a 3-valve feedback-pair has several useful features. A circuit is given of a feedback-pair with a gain of ×100, a frequency range from 8c/s to 8Mc/s, and an output which at mid-band is linear up to 50V R.M.S.

THE performance of a single stage in a wide-band amplifier is best specified by the maximum gain that may be achieved over a given bandwidth, i.e. the maximum "gain-bandwidth" product. For a given valve type the gain-bandwidth product is proportional to g_m/c_o where g_m is the mutual-conductance and c_o the total anode and grid capacitance. Thus the fact that a valve has a high slope does not necessarily mean that it is suitable for wide-band amplification. For example consider the EF55 (CV173) and the EF91 (CV138), which have slopes of 12·0 and 7·5mA/V respectively. With the EF55, $c_o = 15 + 12 = 27$pF and g_m/c_o is 0·45mA/V/pF; for the EF91 the parameter is 0·69 which is 50 per cent better. The EF55 is, of course, capable of handling higher signal levels and is suitable for use in an output stage.

In a review of wide-band amplifiers published in 1939, Wheeler[1] showed that the maximum gain-bandwidth product obtainable from a single stage in a practical amplifier also depends on the coupling. For a four-terminal filter-type coupling the performance is better than with a choke-compensated load and much better than with a simple resistive load. The high-frequency cut-off is more rapid with the filter arrangements than with a simple resistance, and, when numerical comparisons between the different types of coupling are made, it is important to specify the method of defining bandwidth. Wheeler[1], for instance, defines the bandwidth of a stage in a low-pass amplifier as the frequency at which the response is 95 per cent of its mid-band value; on this basis he shows that a multi-element filter may give a gain-bandwidth product almost five times as great as that for a simple resistance. If, however, we define bandwidth as the frequency at which the response is 70·7 per cent (i.e. 3db down) the performance of the filter is only about twice as good. A rigorous solution to the gain-bandwidth problem has been obtained by Hansen[2]; the results do not differ significantly from those of Wheeler. A filter-coupled amplifier, suitable for low signal levels, was described in this Journal by Plowman[3].

Although the filter-coupled amplifier will give an extended frequency response, the construction of the filter is troublesome and, as there is no feedback, the linearity is poor. A simpler approach is to use a three-valve feedback pair; this consists of two amplifying stages feeding a cathode-follower output stage. Feedback is applied from the output terminal to the cathode of the first valve. The gain-bandwidth product is better than that obtainable with simple resistive loads (and no feedback), but is somewhat inferior to that achieved with filter-coupling. The feedback-pair has been used. both in this country and in the U.S.A., for pulse-amplifiers in nuclear physics research, and an account of some of its properties has been given by Gillespie[4]. Schultz[5] and by Elmore and Sands[6]. Capacitance-coupling is always used between the first and second valves, while the coupling to the output stage and in the feedback loop may be either through capacitors or direct. A pulse amplifier with two feedback-pairs in cascade has been described by Jordan & Bell[7], this amplifier has capacitance-coupling to the output stage, but direct coupling in the feedback-loop. The amplifier to be described has direct-coupling for both the output stage and the feedback-loop; this avoids oscillation troubles and makes it possible to obtain a good low-frequency response without large capacitors.

The Rise in Response at High Frequencies

In the feedback-pair the gain tends to rise at frequencies near the upper limit of the pass-band. The cause of this effect was first analysed by Everest and Johnston[8] who showed that the magnitude of the response-peak was a function of the cut-off frequencies at the anodes of the first and second stages. They considered the circuit conditions for which the response-peak occurs at the highest frequency. In order to compare their results with later work it is convenient to define two quantities, firstly the feedback-factor $F = 1 + A_o\beta$ where A_o is the gain without feedback and β the feedback fraction, and secondly the staggering-coefficient K which is the ratio of the cut-off frequencies at the first and second anodes ($K > 1$). Using these symbols Everest and Johnston's result is simply $F = 1 + K$. The problem was later discussed by Brockelsby[9] who found the conditions for the best response *without* a rise at the upper end; the result is $F = (1 + K)^2/2K$. Subsequently Flood[10] showed that, with a step-function input, this condition resulted in a slight overshoot and furthermore. that the overshoot did not occur when $F = (1 + K)^2/4K$. It is interesting to note that when the feedback-factor F is fairly large the three conditions are nearly $F = K$ (Ref. 8). $F = K/2$ (Ref. 9) and $F = K/4$ (Ref. 10). Thus if we require an amplifier free from overshoot[10] the staggering-coefficient must be at least four times the feedback-factor. The stray capacitances at the anodes of the first and second stages are usually about the same so that the coefficient K is roughly equal to the ratio of the anode loads; even with this ratio at large as 40 the feedback factor must be less than about 10. In a practical amplifier a high value of K will cause the gain A_o to be much less than when the loads are about equal ($K \approx 1$). These considerations show that if we try to obtain optimum performance by staggering the cut-off frequencies the resulting amplifier will not have sufficient feedback to give much improvement in the linearity and gain-stability at the centre of the pass-band. Fortunately, the difficulty may be overcome by correcting for the response-rise with a capacitor in the feedback path. This enables us to avoid staggering so that the gain A_o is large, giving a high value for the feedback factor $1 + A_o\beta$. A compensating capacitor is used in the amplifier of Jordan & Bell[7] and in the British A.E.R.E. amplifier; the theory is worked out in the paper by Flood[10]. At the low-frequency end of the pass-band the coupling between the first and second stages forms the only time-constant and a response-peak cannot occur.

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Circuit Description

The circuit diagram of an amplifier built on this principle is shown in Fig. 1. The valves V_1 and V_2 are both type EF91 and the output cathode-follower V_3 is type EF55. The 10kΩ resistor R_2 and 8·0μF capacitor C_3 provide a decoupled H.T. supply of 200V for the anode of V_1 and the screens of V_1 and V_2. Starting with V_2 the D.C. conditions in the amplifier may be worked out from the valve characteristics. V_2 has 200V on its screen and 150Ω in its cathode; this gives an anode current of 8mA and 125V on the grid of V_3. The cathode load of V_3 is 3·3kΩ and, allowing 5V for the grid-base, the cathode voltage is about 130V. The corresponding cathode current is 40mA and the bias across the 33Ω resistor R_{11} is 1·6V with a space current in V_1 of 8mA. The anode current of V_1 is about 6·5mA and its anode is at 135V. From the above discussion of the D.C. conditions it will be seen that valve tolerances must be considered rather more carefully in a feedback-pair than in an ordinary capacitance-coupled amplifier. The D.C. conditions are to some extent stabilized by permitting the screen potential of V_1 and V_2 to be controlled by the anode current of V_1. The mechanism of the stabilizing action may be explained by considering what happens when the emission of V_2 is low. Under these conditions V_3 takes an increased current and the bias across R_{11} becomes greater, thus reducing V_1 anode current; the reduced current in R_2, however, causes the screen voltage of V_1 and V_2 to rise; this increases the anode current in V_1 and V_2 and tends to oppose any change in D.C. level. Fortunately the D.C. conditions have been found to change but little with different valves and it is therefore unnecessary to provide for adjustment of V_2 anode current.

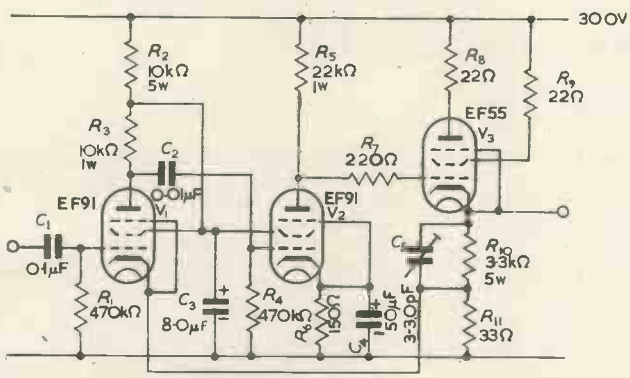

Fig. 1. Circuit diagram

Except for R_2, which is wire-wound, all resistors in the amplifier are of the carbon type. The 3·3kΩ cathode resistor R_{10} is made up of three 10kΩ 2W resistors in parallel. The 0·01μF coupling capacitor C_2 is mounted in the wiring to reduce stray capacitance, and the resistor R_{11} is soldered directly between the valveholder tag and the chassis to minimize the inductance in the cathode circuit of V_1.

The measured value of the gain A_0 is about 10,000 as compared with the theoretical value of $g_m^2 R_3 R_5 = 12{,}000$. The gain with feedback is slightly less than $(R_{11} + R_{10})/R_{11}$ and it is convenient to select the resistor R_{11} so as to make the net gain exactly × 100. The compensating capacitor C_5 is adjusted for the best frequency response; the capacitance required is about 21pF. Care should be taken not to load the output terminal with too much capacitance as the response will then be altered at high frequencies[5,6].

Frequency Response

The frequency response of the amplifier is shown in Fig. 2. The response is substantially uniform from 15c/s to 5Mc/s and falls by 3db at 8c/s and 8Mc/s. It is interesting to compare this performance with that which would be expected from two stages having the same overall gain, but with resistive loads and no feedback. The slope is 7·5mA/V and a stage gain of 10 is obtained with loads of 1 300Ω. The measured capacitance C_0 at V_1 anode is 15·6pF, of which 11·0pF is due to the output capacitance of V_1 plus the input capacitance of V_2. When the cathode-follower V_3 is cold, C_0 at V_2 anode is 23·9pF and with V_3 hot (not measured) it is probably about 16pF. The calculated overall response is 3db down at 4·9Mc/s which is not as good as the value of 8Mc/s obtained in the case of the feedback-pair.

Gain-Stability

In a feedback amplifier of this type the no-feedback gain A_0 is a function of frequency. Near the two ends of the pass-band, A_0 is much reduced, although the amplifier gain remains very nearly constant at $1/\beta$. Thus gain-stability and linearity will both be better at frequencies well within the pass-band than at frequencies near the cut-off points. For the amplifier described the frequency range over which A_0 is approximately constant is 50c/s to 500kc/s. In this range an alteration of heater voltage from 5 to 7V, or a H.T. change from 250 to 350V, affects the gain by less than 0·5 per cent. However, for a frequency well *outside* the passband the feedback is negligible and the change in gain is much larger. The following table shows the effect on the amplifier gain at 15Mc/s of the same supply variations. It will be seen that the gain now alters by approximately 30 per cent instead of 0·5 per cent as previously.

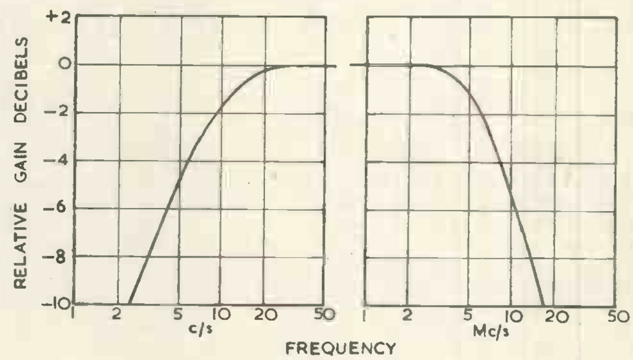

Fig. 2. Frequency response

H.T.	Percentage Gain	Heater	Percentage Gain
250V	86	5·0V	81
300V	100	6·0V	100
350V	114	7·0V	113

Linearity

The input-output curve for a signal at 50kc/s is shown in Fig. 3. For input signals in the range up to 0·5V R.M.S. the output does not differ from 100 times the input by more than 0·5 per cent. As the input level is increased above 0·5V the amplifier overloads on the peaks of the waveform in an approximately symmetrical manner. For the reasons discussed in the previous paragraph the linearity curve will be the same at frequencies from 50c/s to 500kc/s with a progressive deterioration outside this band. It will be noted that both gain-stability and linearity (i.e. distortion) are excellent in the audio-frequency range. The output impedance is 10Ω or less in the range 50c/s to 500kc/s rising to $1/g_m$ (g_m is the slope of V_3) at the extremes of the pass-band.

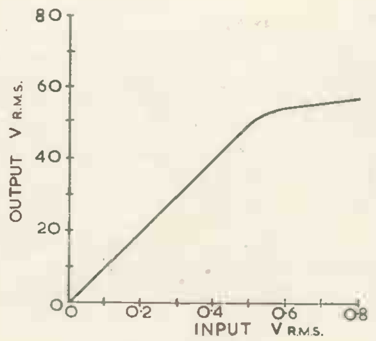

Fig. 3. Linearity

Applications

The amplifier was originally used to raise the output level of a signal generator from 50mV to 5V for some work on a capacitance pick-up. Subsequent uses have been as a linear pre-amplifier for a valve-voltmeter, to drive a dynamometer instrument for precision voltage measurement, and as an output stage in equipment measuring ultrasonic noise. The circuit is economical in components, needs no coils and has only one adjustment.

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A New Magnetic Attenuator

By M. Lorant

An inexpensive type of microwave attenuator for coaxial transmission lines recently developed by the U.S. National Bureau of Standards utilizes a magnetic field to obtain instantaneous changes in attenuation. Its operation depends on the interaction between the electromagnetic field within a transmission line, which contains microwave energy-dissipating material, and an external magnetic field applied perpendicularly to the axis of the line. As a result of this interaction, the loss characteristics of the dissipative material are substantially altered. The new Magnetic Attenuator requires no movable components, mechanical controls, or slotted sections in coaxial transmission line and may be operated either manually or automatically from a proximate or remote position.

The unit is simple in construction: it is composed only of a slug of some highly permeable and resistive ferromagnetic material placed within the field of an electromagnet. The significant feature of the device is the change in the loss properties of the dissipative material when it is subjected to a magnetic field. Because the magnetic field is produced by an electromagnet, its magnitude can be changed simply and precisely by varying the current in the field coils. In addition, the control characteristics are linear over a substantial range. An investigation of materials such as polyiron and ferrites (with electrical resistivities from 10^2 to 10^4 ohms/cm) indicated that the loss characteristics not only depend upon the composition and length of the material but increase with increasing frequency.

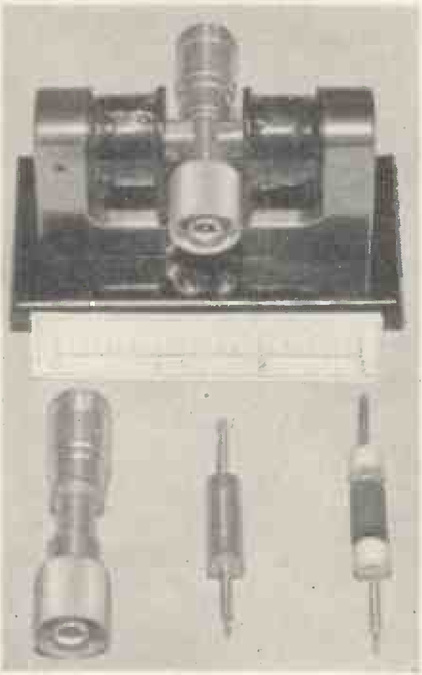
The size of the new U.S. National Bureau of Standards Magnetic Attenuator for ⅜-inch coaxial transmission lines is only 4 by 4 by 2 inches. The dissipative material, a cylinder of polyiron, is about ½ inch long and ⅜ inch in diameter. A recessed conductor hole for the centre conductor is drilled into the cylinder, ceramic insulators are placed at the extremities, the whole assembly is encased in a metal sheath, and connector pins are fastened to the ends of the centre conductor. Standard male and female type N coaxial connectors complete the assembly.

An experimental model which uses polyiron as the dissipative element was operated at frequencies from 1 000 to 3 000Mc/s. Variations in the losses of the polyiron were produced which were large enough to reduce the attenuation 60 per cent, change the power by a ratio greater than 60 : 1, with a voltage standing-wave ratio always less than 1·5.

When the magnetic field is rotated 360 degrees about the axis of some of these coaxial attenuators, a position may exist where the field has its maximum effect. For instance, when a magnetic field of constant intensity was rotated about the axis of a coaxial attenuator operated at 3 700Mc/s, changes in attenuation of 17db were obtained. However, this rotational phenomena does not exist for all materials in these attenuators.

Many applications of this magnetic phenomenon are immediately evident. An audio source can be used to vary the electromagnet current which produces a changing field in the attenuator and consequently amplitude-modulates the R.F. signal. The resultant modulation envelope includes the predominant second and higher order harmonic frequencies of the audio frequency field. However, these harmonics can be readily eliminated by employing a D.C. bias which the A.C. field oscillates.

It is equally adaptable as an output stabilizer for microwave oscillators. The unit can be part of a degenerative feedback circuit in which the magnitude of the field produced by the electromagnet is controlled by a small amount of R.F. power taken from the coaxial transmission line. Another magnetic unit may also be utilized in such a feedback network. The rectified control voltage coupled from the transmission line may be applied to a magnetic amplifier which controls the electromagnet field directly.


A typical attenuator (top)
The component parts (bottom)

Among the latest group of materials under study are magnetic ferrites, which yield greater attenuation changes for a given electromagnet current than does polyiron. These ferrites should thus make possible the use of smaller currents to produce the same changes of attenuation.

A Hard Valve Pulse Generator

By D. A. Levell*, B.Sc.

The operation of the circuit is described in detail. The observed characteristics and waveforms of a triggered pulse generator producing pulses of width variable from 0·7 to 12·8 microseconds are given. Various modifications to the basic circuit are described, including a modification to make the circuit free-run. To conclude, a list of advantages of the circuit is given, as compared with known multivibrator or phantastron circuits.

THE basic circuit of the triggered pulse generator is given in Fig. 1. The action of the circuit can be considered to pass through the following seven states during one cycle of operation.

(A) Wait state which exists until a signal is applied.

(B) Amplifier state until anode current is initiated in V_1.

(C) Amplifier state until anode current is initiated in V_{2a} of sufficient amplitude for the dynamic loop gain of the circuit to exceed unity.

(D) Regenerative state until the suppressor grid of V_1 is driven to conduction.

(E) Rundown state until anode current is reinstated in V_{2b} of sufficient amplitude for the dynamic loop gain of the circuit to exceed unity.

(F) Regenerative state until anode current in V_1 is cut off.

(G) Flyback state until the circuit is restored to the wait state.

The typical circuit waveforms given in Fig. 2 have been divided into these seven states.

In the wait state V_{2b} is conducting and passes sufficient current through R_9 and R_{10} to cut off or reduce to a small value the anode current of V_{2a}. Valve V_1 is used in a circuit similar to the known cathode-coupled phantastron circuit[1,2], the two important differences in the present circuit being that R_3 is lower than the usual value required for a cathode-coupled phantastron and R_6 is returned to a fluctuating potential instead of to a constant potential. V_1 initially passes grid and screen currents, and component values are chosen so that the potential drop produced across R_3 exceeds the potential across R_{10} by more than the suppressor grid base of V_1. Thus no anode current flows in V_1 and the anode is at the potential of the H.T. supply.

Let it be assumed that a small negative trigger pulse is applied to the grid of V_{2b}; an amplified positive pulse is then produced on the suppressor of V_1. When a certain pulse amplitude is reached anode current flows in V_1, and the resulting potential drop across R_4 is fed on to the grid of V_1 via C_1. The screen current in V_1 is reduced and the screen potential rises. This potential rise is fed on to the grid of V_{2a}, via C_3 and R_7, so that anode current in V_{2a} is switched on or increased. The cathode potential of V_2 is increased, causing a reduction in the current flowing in V_{2b}, and effectively increasing the trigger signal.

When the input signal is increased beyond a certain amplitude, the dynamic loop gain of the circuit exceeds unity and regeneration occurs until V_1 is driven into suppressor grid current. The circuit component values may be chosen so that for this condition V_{2a} is driven into grid current and a large positive rise is produced on the cathode of V_2.

The grid potential of V_1 falls to that value which limits the anode current of V_1 to the sum of the currents flowing through R_1 and R_4. Grid current no longer flows in V_1 and C_1 discharges at a rate $dV/dt = i/C_1$ where i is the current flowing through R_1 and C_1. If R_1 is returned to a voltage E_1 which is much larger than the grid base of V_1, the current i is nearly constant during the discharge,

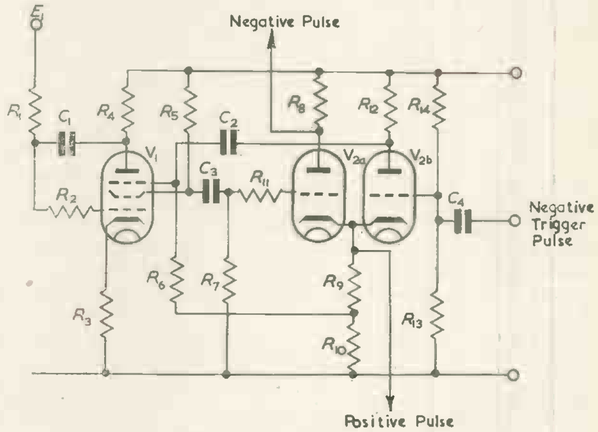


Fig. 1. The basic circuit

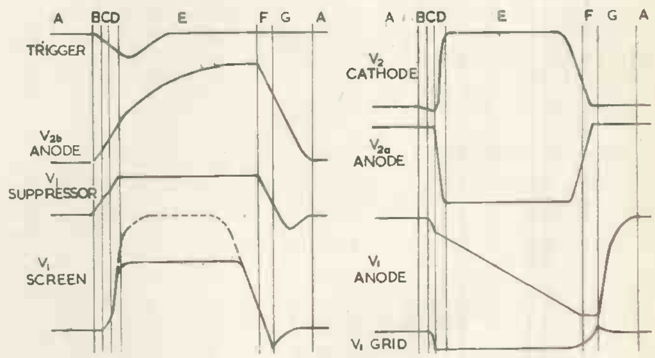


Fig. 2. The waveforms of the circuit shown in Fig. 1

and the rundown of anode potential is nearly linear with time. During the rundown the anode impedance of V_1 must fall to maintain the currents through R_1 and R_4, thus the grid potential of V_1 rises with time. The screen potential of V_1 will correspondingly fall with time, but by a suitable choice of valve and component values the fall of screen potential can be kept small until the anode potential of V_1 falls to a few volts above the cathode potential. When this region is reached, the gain of the pentode decreases rapidly with time and the rate of fall of the screen potential increases. The anode current in V_{2a} is reduced by the falling screen potential so that the cathode potential of V_2 falls. Anode current is re-initiated in V_{2b}

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when V_2 cathode falls below a certain potential. The resulting falls of V_{2b} anode and V_1 suppressor potentials cause a reduction of V_1 anode current and a corresponding rise of V_1 grid potential. When the anode current produced in V_{2b} is of sufficient amplitude for the dynamic loop gain of the circuit to exceed unity a regenerative action takes place until the anode current in V_1 is cut off.

The capacitor C_1 charges exponentially through R_4, R_3 and the grid-cathode path of V_1 until the anode voltage of V_1 reaches the potential of the H.T. supply. The flyback is then complete.

The coupling time-constant C_2R_6 has been assumed to be short compared with the run time of the pulse generator, but long compared with the rise time of the trigger signal. If R_6 were returned to a point of constant potential instead of to the tap on the cathode load of V_2, the resistor R_3 and the constant potential would need to be chosen in value so that the cathode voltage of V_1 would be less than the suppressor potential at all times during the rundown. In addition, during the wait state the cathode potential would have to exceed the constant potential by an amount sufficient to cut off the suppressor. This condition can be realized, but the value of cathode resistor required is generally so large that an appreciable reduction of the pentode stage gain during the rundown occurs. If linearity of the rundown of V_1 anode is important, the resistor R_3 should be kept as small as possible. This is accomplished in the given circuit by holding the suppressor on during the rundown by a fraction of the positive pulse developed on the cathode of V_2.

The leading edge of the screen waveform is purposely drawn as an exponential rise to take into account stray capacitance present on the screen. Due to the limiting action of V_{2a} during the pulse, the rise time of V_2 cathode pulse is less than the rise time of the screen load impedance. The broken curve shows the effective screen waveform fed on to the grid of V_{2a} and the continuous curve shows the actual waveform present on the screen when the grid current passed in V_{2a} is taken into account.

It will be realized that small positive trigger pulses applied to V_{2b} grid have negligible effect on the circuit and cannot cause triggering. It is, however, possible to trigger the circuit by a positive pulse applied to V_1 suppressor through a small coupling capacitor. The trigger sensitivity to a positive pulse is less than that for a negative pulse, since V_{2b} does not operate as a trigger pulse amplifier for this condition.

Practical Circuit

The component values used in a practical design were as follows:—

R_1	91kΩ	R_8	2·2kΩ	C_1	10pF
R_2	470Ω	R_9	1·8kΩ	C_2	0·01µF
R_3	1·8kΩ	R_{10}	330Ω	C_3	300pF
R_4	330kΩ	R_{11}	470Ω	C_4	300pF
R_5	20kΩ	R_{12}	20kΩ		
R_6	220kΩ	R_{13}	18kΩ	V_1	CV 329 (6F33)
R_7	100kΩ	R_{14}	470kΩ	V_2	CV 858 (6J6)

The circuit was connected to an H.T. supply of 280 volts. A negative pulse of width 3·5µsec, rise time 0·25µsec, and repetition time 350µsec was used to trigger the circuit. The observed characteristics of the circuit for several different values of the potential E_1 are given in Table 1.

The pulse width is taken as the interval between the start of the rise of the leading edge, and the start of the fall of the trailing edge of the cathode pulse of V_2. The fall of the pulse amplitude from the peak value reached until the onset of the trailing edge was observed to be less than 2 per cent.

The negative pulse on the anode of V_{2a} was approximately the same amplitude as the cathode pulse on V_2.

When E_1 was reduced below 12 volts the circuit free-ran.

The trigger sensitivity is taken as the smallest amplitude of the negative trigger pulse required to ensure good operation of the circuit. If the trigger signal is reduced a little below the amplitudes given, the circuit will frequency divide due to the finite coupling time-constant R_7C_3.

TABLE I

E_1 (Volts)	V_2 CATHODE PULSE: Width (µsec)	Amplitude (Volts)	Rise Time 10-90% (µsec)	Fall Time 90-10% (µsec)	Trigger Sensitivity (Volts)
280	0.7	72	0.3	0.3	5.0
137	1.55	78	0.3	0.4	4.1
42	5.0	78	0.3	0.8	2.5
21	10.5	77	0.3	2.1	2.0
15	12.8	76	0.3	3.5	1.4

Modifications to the Basic Circuit

The following list of modifications which may be made to the circuit for particular applications is by no means exhaustive. The given examples have actually been used by the author.

(a) FREE-RUNNING PULSE GENERATOR

R_6 is returned to a positive potential and the time-constant R_6C_2 is chosen to determine the pulse space time (see Fig. 3).

(b) D.C. COUPLING

The A.C. couplings C_3R_7 and C_2R_6 may be replaced by conventional D.C. couplings when a negative supply line is available (see Fig. 3).

(c) IMPROVEMENT OF THE LINEARITY OF THE PHANTASTRON RUNDOWN

The cathode of V_1 is connected directly to earth. An extra resistor is connected between the suppressor of V_1 and a negative supply. By a suitable choice of this resistor value and the supply potential the anode current in V_1 is cut off during the wait state and held on during the rundown.

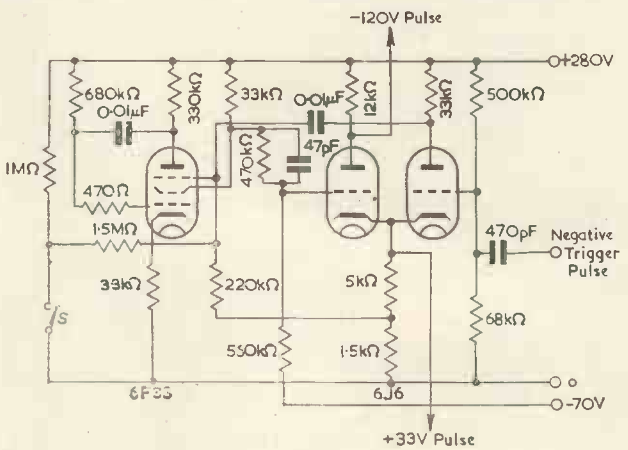

Fig. 3. A modified circuit

When switch S is closed and a trigger signal is applied, this circuit produces pulses of 5msec width. When S is open the pulse generator will free-run at a repetition time of 10msec.

Advantages of the Circuit

The following list of advantages of the circuit has been compiled to show how the circuit compares with known multivibrator and phantastron circuits. It should be understood that the given circuit often requires more supply current than simpler circuits and an extra valve.

(a) Large output pulses of either polarity can be obtained at relatively low impedance.

(b) The trigger sensitivity is high for negative trigger signals.

(c) Negligible kick-back on to the trigger source occurs for negative trigger signals.

(d) The run time can be varied over a large range by altering a D.C. potential only.

(e) A large negative sawtooth waveform is generated, this makes the circuit suitable as a sweep generator for an A or B-scope display unit.

(f) The circuit can be triggered by pulses of either polarity.

Acknowledgment

The author thanks Messrs. A. C. Cossor Ltd., for permission to publish details of this circuit, which the author designed in the course of development work at the Research Laboratories of the Company.

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A Synchronizing Circuit for Variable Input Voltages

By P. A. V. Thomas*, B.Sc.

IT is not uncommon in oscillography and allied work that a series of voltage waveforms have to be observed and that the oscilloscope time-base has to be synchronized from the signal itself; with the normal form of synchronism using direct signal injection through a potentiometer the synchronizing control has to be re-adjusted to obtain a satisfactory display as the voltage to be applied to the time-base valve(s) should be approximately constant. As a display unit was being built to handle a variable amplitude recurrent signal a simple circuit was developed to overcome the difficulty.

The basic circuit, for use where the input signal is sinusoidal, is as shown in Fig. 1(a) and consists of a rectifier

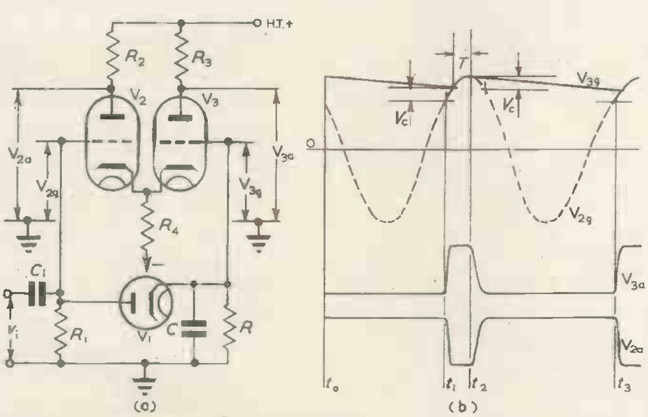

Fig. 1. The basic circuit

and a comparator stage. The input signal V_i is first rectified by means of the diode V_1 together with the load resistor R and reservoir capacitor C giving the voltage V_{3g} in Fig. 1(b); this voltage is then compared with the voltage V_{2g}—identical to the input voltage—by means of the valves V_2 and V_3. at time t_0, V_3 is conducting owing to its grid voltage being more positive than V_{2g}, so that the voltage of the common cathode connexion V_k will be slightly above V_{3g} by cathode-follower action.

At time t_1, V_{2g} reaches a value equal to $V_k - V_c$ (where V_c is the grid base of V_2) and V_2 begins to conduct so that V_{2a} falls and V_{3a} rises, the latter due to the common cathode current being equally shared if R_2 equals R_3. This condition remains until just before time t_2 as the two grid voltages are equal during this period.

At time t_2, V_{2g}, having begun to fall due to the nature of the input waveform, again reaches the voltage $V_k - V_c$ (higher than at t_1 due to C having been recharged during time T) so that V_2 becomes cut-off again, its anode voltage returning to H.T.+, while V_{3a} falls to its original value.

This process is then repeated at time t_3, etc., producing a series of positive pulses (at V_3 anode) and negative pulses (at V_2 anode) suitable for synchronizing a time-base as their amplitudes are independent of the input signal amplitude, providing it is not too small. The time of synchronism depends upon the slope of the pulse front and thus for consistency the rise time should be as short as possible; to do this the signal should be as large as possible and the comparator valves grid-bases as short as possible, the former generally being obtainable at the point where the signal is applied to the cathode-ray tube deflexion plate.

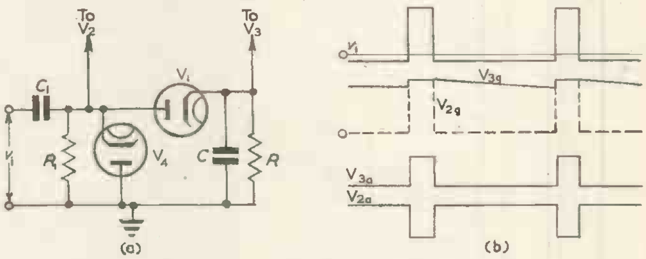

Fig. 2. Circuit for positive pulse inputs

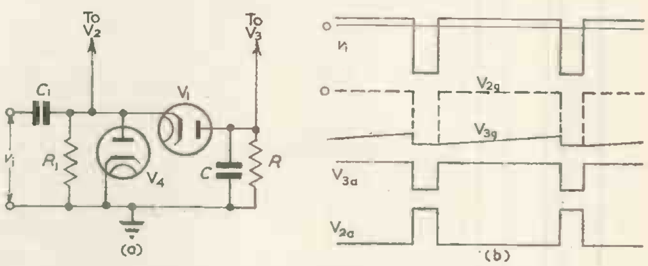

Fig. 3. Circuit for negative pulse inputs

So far only sinusoidal voltage inputs have been considered but if the input is of pulse form a D.C. restorer should be included as shown in Fig. 2 (for positive pulse inputs) and Fig. 3 (for negative pulse inputs) the method of operation being as before. The front of the pulse generated is now much sharper, being as the input signal pulse and is thus almost independent of the comparator valve grid-base.

For general use, however, the arrangement of Fig. 1 is recommended particularly, if when using pulses the pulse duration is small compared to the periodic time, in which case the D.C. restorer is not essential.

* *Royal Technical College, Glasgow.*

BOOK REVIEWS

General Network Analysis

By W. R. Le Page and S. Seely. vii + 516 pp. McGraw Hill Publishing Co. 1952. Price 68s.

THIS book is described as an outgrowth from a "second course" in circuit analysis, and from its contents should admirably cover the requirements of a student who knows the basic principles given in physics texts and is proceeding to an honours degree in electrical engineering. Although the book does not profess to deal with specialized problems, being intended to provide the essential techniques for both power and high-frequency circuits, the standard reached is high: matrix methods are introduced, and used almost exclusively in the analysis of polyphase systems by symmetrical components, and on the H.F. side there is a full discussion of impedance and admittance charts, including the Smith chart. The treatment of circuit analysis, in fact, is thorough and comprehensive, and each chapter has thirty or forty problems by means of which the student can consolidate his knowledge. The only topic for which the reviewer looked in vain was the gyrator.

But unfortunately one has the feeling that the student is being kept in blinkers. The most striking example of this is the omission from the book of *electromotive force*. It may simplify the completion of an examination course to make the student work solely in *potential difference*, and the conventions for directions of currents and P.D.'s are admirably set out; but is it fair to send a budding engineer into the world unaware of the ideas and pitfalls associated with E.M.F.? How will he reconcile equation (4-1), $e_1 = L_1 di_1/dt$, with the physicists' rule $e_1 =$ *minus* $L di/dt$ without a discussion of the difference between E.M.F. and P.D.? (The difficulties which some find with these topics can be avoided by teaching the complete statement of electromagnetic theory, that both the gradient of the electrostatic potential and the time-derivative of the vector magnetic potential contribute to the electric force.) Similarly one finds a chapter on operational calculus which practically ignores Heaviside, it being assumed that by now "operational calculus" is practically synonymous with "Laplace transform" (the spelling *LaPlace* occurs only on the publisher's wrapper), and a paragraph on the calculus of residues which does not mention Cauchy. Moreover it appears that the direction of power flow in circuits, and high-frequency transmission lines, are both treated without mention of Poynting's theorem.

This narrowly practical approach is the more unfortunate because there are hardly any direct references from the text to other work. Instead there is at the end of the book a list of 56 numbered references, with a separate key showing which numbers are relevant to the several chapters. A book of this size and high technical level could easily have been made into a useful reference book; but the British student, at any rate, may be reluctant to spend 68s. on a book which is not primarily designed for use as a reference after his examination course is finished.

D. A. BELL

Die Magnetische Schallaufzeichnung in Theorie und Praxis (Magnetic Sound Recording in Theory and Practice)

By Dr. F. Krones. 239 pp. 82 illustrations. Technischer Verlag B. Erb, Vienna. 1952.

THE author of this monograph claims that his is the first comprehensive book on this subject. That may be true as far as publications in the German language are concerned. But as may be seen from the bibliography at the end of the book there exists at least one book each of a similar character in English and French.

And one misses badly in the preface an acknowledgment to what extent the author has made use of S. J. Begun's book which was published in 1949 in the U.S.A. (reviewed in ELECTRONIC ENGINEERING, April 1950, p. 160). Even a quite superficial perusal of the table of contents and of the illustrations shows the great indebtedness of the author to Begun as regards the arrangement of the subject matter, and there are even numerous sections which are merely translations from the previous publication. Of course that does not mean that the book under review is without its own merits; for instance more details are given in the chapter dealing with the playback process, and some of the tables and diagrams are more elaborate. Besides there is more information concerning continental practice, particularly in an appendix dealing with industrial products.

For readers who do not know Begun's book a brief account on the contents of the present book may be of some value. After a short historical review the fundamental concepts of acoustics and magnetism are dealt with. About 70 pages are devoted to the theory of magnetic recording and about 180 pages to the equipment used comprising, the sound carrier, the magnet heads, the electric amplifiers and the driving mechanism. After brief sections on the use of magnetic sound recording equipment for broadcasting purposes and basic requirements which it must fulfil and hints on its proper adjustment, measuring methods and special applications are dealt with. The use of dictating machines, which is of increasing importance is only scantily treated. A bibliography and a subject matter index complete the book, which also contains nine useful tables.

R. NEUMANN

Industrial Magnetic Testing

By N. F. Astbury, M.A., M.I.E.E., F.Inst.P. 132 pp., 41 figs., 12 tables. The Institute of Physics. March 1952. Price 25s.

THIS book is a very concise compilation of information on the subject of magnetic materials from the viewpoint of analysis and method of measurement in this extremely complicated field. The range of source material is demonstrated by the bibliography of 125 references appended.

The seven chapters cover: general concepts of magnetism; the magnetic circuit and its associated electrical circuit; measuring instruments; permeability and hysteresis measurements; power loss measurements and analysis; measurement of complex permeability, using bridge and potentiometer methods; pulse magnetization; permanent magnet testing, and the measurement of magnetic field strengths. Four appendices deal with: M.K.S. units in magnetic measurements; eddy current losses in thin plates; general properties of materials, and some special properties of materials.

While the coverage of test methods is certainly comprehensive, the reviewer feels that the book is biased toward the determination of the basic or academic characteristics of materials, rather than the detailing and interpretation of tests applicable to industrial uses of materials. The analytical parts are those the author considers essential to determining what factors are of relevant magnitude in any approach or measurement; the parts dealing with method are merely a compilation showing what has been done, that the engineer can select and apply for his own particular problems.

The analyses are presented in mathematical terms that may deter the non-mathematical mind from attempting to follow them. Of course, when there are so many variables, only a mathematical presentation can give a really concise indication of relevant values and quantities; and the author gives sufficient explanatory material so that even the non-mathematical individual should be able to extract as much information as will be comprehensible to him, with a little patience.

On the application side, sufficient is said about the various methods dealt with to indicate possible choices for any purpose in hand, whence the relevant references from the bibliography will locate the necessary detail.

N. H. CROWHURST

Dimensional Analysis

By Professor H. E. Huntley, Ph.D. 158 pp. Macdonald and Co. (Publishers) Ltd., London. June 1952. Price 20s.

IN a few hours a student of physics or engineering can read this book and gain a far more complete picture of the utility and limitations of the method of dimensions in theoretical work than can be gained from the short sections in most books. The whole work is choc-a-bloc with examples.

The author soon runs into a problem on which much has been written, whether or not there are just three fundamental units (mass, length and time); a discussion which always reminds the reviewer of the older arguments of the number of elements in nature (fire, earth, water. etc.). The author's attitude to this question is that adopted by most of the successful users of dimensional analysis, that the dimensional independence of a physical quantity depends on the problem and how it is defined in relation to the problem. Thus the dielectric constant or temperature may be regarded as independent units or not just as it is convenient. To illustrate this he gives many examples to show the value of distinguishing in dimensional formulæ between lengths in different directions, and also between mass as quantity of matter and mass as inertia. In this connexion rather more might have been said on the symmetry properties of the problem and of the attempted solution, both of which are relevant. Also one must be careful to check the assumption that a dimensional relationship implies a physical relationship between quantities. Dimensional analysis is in the first place a simple expression of physical insight. For example, in some problems of viscous flow examined in the book formulæ are obtained as if they were completely general, whereas in fact they are limited to streamline flow.

In a few places there is a lack of care in expression, e.g., the example on Kepler's third law on the orbits of the planets suggests that the law has not been understood, but one can forgive this because of the obvious interest and enthusiasm of the author, and the clarity of his descriptions.

G. J. Kynch

Wireless Fundamentals

By E. Armitage, M.A., B.Sc. 368 pp. 334 figs. Sir Isaac Pitman and Sons Ltd. July, 1952. Price 18s.

MANY elementary radio textbooks suffer from an overcrowding caused by the desire for completeness. In this way descriptions of the atomic theory, discussions on "j", trigonometrical definitions, etc., jostle for position with matter more pertinent to the student. Mr. Armitage has avoided this by deciding on the limitations of his readers and working within those boundaries. His potential reader is one who, while knowing Ohm's law and the effects of an electric current, has no understanding of calculus, and its application to radio engineering.

After an introductory chapter giving a broad outline of wireless communications, Chapter II deals with the diode and the triode. The valve constants are defined and related, and the ideas of voltage amplifiers, dynamic characteristics and load lines are introduced. Chapters III and IV deal with resistance and capacitance in D.C. circuits, and Chapters V and VI treat elementary A.C. theory. Chapter VIII on "Coils and their Behaviour" concludes one coherent block of work.

Chapter VIII on "Power Supplies" uses the knowledge obtained in the previous chapters, and applies it to the problems of the supply of D.C. from an A.C. source. In a similar way Chapter IX, "The Triode as a Voltage Amplifier," uses previously acquired knowledge to extend the reader's understanding. Chapter X, on "Further A.C. Theory", deals competently with tuned circuits, Q. power in A.C. circuits and power factors. This leads logically on to Chapter XI—"The Valve as an Oscillator"—which discusses the normal oscillators (Meissner, Hartley, Colpitts) in a conventional manner. The scope of this chapter probably could have been increased usefully to include a statement and derivation of the maintenance equation.

Chapter XII treats tetrodes and pentodes and R.F. amplification, Chapters XIII and XIV the carrier wave, its generation, modulation and properties, and Chapter XV detection and A.F. amplification. A brief discussion (described by the author as a "look-ahead") on the superhet is found in the concluding chapter of the book. There are four appendices, a group of examples complete with answers, and a comprehensive index.

The most unfortunate weakness of the work as a whole lies in the very poor descriptions of the construction of modern radio components. The author would seem to have little first-hand knowledge of the manufacture of any radio component. Thus, paper capacitors are said to be made from "... thin metal, usually tinfoil," mica capacitors are alleged to have a lower capacitance value of 100pF, and the ceramic capacitors described bear no relation to practice. Coils and iron dust cores receive scant attention and valves rely mainly on line-drawings derived from another textbook.

Despite this failing, Mr. Armitage is to be congratulated on producing a most useful textbook. Its unconventional subject-order justifies itself completely, and teachers of radio engineering at this level would be well advised to consider whether this book should not be adopted as a working text. It is certainly in the reviewer's opinion, the best new book on this subject which has been published for some time.

K. G. Lockyer

Sound Recording and Reproduction

By J. W. Godfrey and S. W. Amos, B.Sc., A.M.I.E.E. 272 pp. 176 figs. 10 plates. Iliffe and Sons Ltd. 1952. Price 30s.

THIS book has been written primarily as an instruction manual for the use of engineering staff of the BBC, but it will be of value to all interested in the technique of sound recording.

The principles of electrical recording and reproduction are first set out. Disk recording is then discussed, with detailed descriptions of the BBC and American Presto equipment now in operation in British broadcasting services, followed by chapters on the reproduction of disks, and pressings and the processing of disks. The principles of magnetic recording are next explained, with descriptions of the Marconi-Stille, Magnetophon and E.M.I. magnetic systems which have been used at different times by the BBC. The book then deals with recording on film, and describes the Philips-Miller film equipment as used by the Corporation. There are a number of appendices containing reference information not readily available elsewhere, and the illustrations comprise many photographs, diagrams, and some useful graphs.

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BUTTERWORTHS

ELECTRONIC EQUIPMENT

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

Constant Frequency Supply Equipment

(Illustrated below)

THE Radio-Aid constant frequency supply equipment has been developed to provide an alternative source of A.C. power having a higher degree of frequency stability than that generally provided by the public supply mains under present circumstances. Applications of the equipment include: the operation of electric synchronous clocks and timing equipment; the operation of stroboscopic lamps and constant speed or speed measuring equipment, and as a source of supply for laboratory and scientific equipment of all types.

The constant frequency is initially provided by a quartz crystal oscillator. The frequency of this oscillator is then divided by a series of electronic circuits until the desired supply frequency, usually 50c/s, is attained. At no stage in this process is a division made by a factor greater than three, and subsequently the supply frequency is filtered to remove unwanted harmonic content and ensure a satisfactory waveform. It is then fed into a power-amplifier, where the level is progressively built up to the specified power output to be provided by each particular equipment.

The constant frequency equipment comprises a constant frequency generator unit, an amplifier unit and a power unit. A control panel is also included, and carries the on-off switches, fuses and pilot lamps only. A blank unit completes the assembly, which may be used to carry a second generator unit or other special provisions for individual requirements. The whole equipment is housed in a totally-enclosed steel rack, and doors are provided at the back and sides. Standard P.O. type panels are employed.

The normal 50c/s equipment employs a driving crystal having an initial frequency of 72·9kc/s. The frequency tolerance at 50c/s output is ±0·01 per cent. This may be set to within ±0·001 per cent by means of an internal electrical trimming adjustment after the equipment has been in operation for a few months ageing period. The frequency is stable to within 0·001 per cent also for variations in the supply mains frequency up to ±5c/s and ±10 per cent in voltage and for those temperature variations normally encountered in an air-conditioned building. In cases where larger variations are anticipated, it is advisable for the crystal to be oven-controlled. With this provision, a frequency tolerance of one part in 10^6 is available to special order.

Three standard designs of amplifier unit are available: a 10 watt unit for timing applications, etc., where only limited power is required, or as a driver unit to feed external amplifiers or apparatus; a 50 watt unit capable of 50 watt output at low distortion in a suitably matched load, and up to 75 watts in applications where waveform is less important, provided that the supply mains voltage is normal; and a 100 watt unit providing an output of from 80 to 130 watts under the above circumstances. The 10 watt unit is normally designed to work into a 600 ohm line, but any other impedance can be provided to order. The 50 and 100 watt units are each fitted with variable-ratio output transformers, and in most applications are connected to deliver nominally 230 volts A.C. into loads of from 600 to 1 200 ohms.

**Radio-Aid, Ltd.,
29 Market Street,
Watford, Herts.**

"Slow Motion" Stroboscope

THE new Dawe "Slow Motion" Stroboscope Type 1206 is designed to enable test pieces on a vibration table to be viewed in slow motion, independent of the drive frequency. The equipment consists of a high intensity stroboscope, together with an oscillator for driving a power amplifier and vibration generator.

The stroboscope can be driven either at the same frequency as the oscillator, or, alternatively, at a constant difference frequency. In the first case the component vibrated appears stationary when viewed with the stroboscopic light; while under the latter condition a stroboscopic "slow motion" effect is achieved, irrespective of the oscillator frequency used to drive the vibration generator. This feature is useful in the examination of components and assemblies subjected to vibration tests, as it is possible to study in detail the individual resonances which may arise as the frequency of vibration is varied. By using a special circuit for the flash tube a repetition rate of 500c/s is achieved in the equipment.

The oscillator has a frequency range of from 10 to 500c/s, and an accuracy of ± 1½ per cent ± 0·5c/s. Its output is 15 volts R.M.S. sine wave to feed the power amplifier driving a vibration generator. The frequency of the stroboscope is locked to that of the oscillator, but has a constant frequency difference of 0, 0·5, 1 or 2c/s selected by a panel control. A xenon filled flash tube giving a white light is employed, which has a flash duration of approximately 40 microseconds. The power supply is 200-250 volts, 50-60c/s.

**Dawe Instruments Ltd.,
130 Uxbridge Road,
Hanwell, London, W.7.**

Alexander Equipment's Decals

THIS firm is producing a book of decals or transfers for use by manufacturers of specialist equipment, or in laboratories and repair establishments. One section has also been included primarily for the amateur. The type is clear, and the letters are approximately ⅛in. high.

Although this method of marking electronic equipment is not new, the use of these books of transfers is economical, and an advantage is that the decals can be applied to equipment at any location or in any position.

To apply a decal the surface to which it is to be fixed should be cleaned thoroughly. Then the decal and the surface are both damped, and the decal placed in position. A stiff card is placed over it to remove surplus moisture and air bubbles, and the decal is left to dry for about half an hour. Afterwards the backing paper is taken off and the tissue thoroughly wet to remove it. A different type of decal is available for surfaces with a crackle finish.

In the book, the decals are divided into sections to cover: communications, audio, oscilloscopes and television, radar and navigation, and general electronics. There are also included decals of the Greek alphabet, and of numbers, words and abbreviations in common use.

**Alexander Equipment, Ltd.,
Child's Place, London, S.W.5.**

Helvin Cable Straps

A NEW cable strap has recently been produced by Hellermann Electric Ltd. It is made from strips of plasticized P.V.C., which have holes punched in them at regular intervals. A plastic stud is supplied with each strip, and this joins together any two of the holes to form a strap round the cables.

The strap can be fitted to any size of loom and is available in any required length. It enables cables to be added or withdrawn as necessary because it can be tightened or loosened.

**Hellermann Electric Ltd.,
Tinsley Lane,
Crawley, Sussex.**

Saunders-Roe Technograph Foil Strain Gauge

(Shown below left)

THE Saunders-Roe Technograph foil strain gauge has been developed jointly by Saunders-Roe Ltd. and Technograph Printed Circuits Ltd. for applications where centrifugal and vibratory forces are of a high value.

The gauge consists of a robust, thin, insulating lacquer film, to one surface of which is bonded a conductive grid pattern of homogeneous metal foil. The grid pattern is "printed" in the sense that the method of production is analogous to a printing process. Fractures of the grid connexions are avoided by enlargement of the ends of the grid element to form substantial connecting tags, and to these the lead-out wires are sweated.

Two types of foil are used for the grid, copper-nickel and gold-silver, with gauge factors of approximately 2·0 and 2·5; these are made up into gauges having resistance values of 40 ohms and 230 ohms respectively.

Several advantages accrue from this method of strain gauge manufacture, which include: a high degree of transverse rigidity and a facility for rapid build-up of stress along the gauge due to the substantial increase in pattern width at the grid ends; the effective "gauging" length of the pattern is higher, and the cross sensitivity lower than can be achieved in wire strain gauges of equal length; the very thin element reduces the shear lag in strain transmission from specimen to gauge to the minimum; the foil gauge can accept a greater electrical power input than the wire gauge due to the high ratio of contact surface area to conductor cross-sectional area, and the flexibility of the lacquer film enables the gauge to be readily applied and secured to specimens which are normally difficult to strain gauge on account of their shape or size, e.g. small control rods and tubes.

The foil strain gauge should prove particularly useful where space and temperature considerations are important. The nature of the lacquer film of the gauge is such that, with suitable adhesives, measurements at temperatures in the 150°-170°C range should present no difficulties. The manufacture of gauges to special order using a silicone lacquer base to cater for higher temperatures is envisaged.

Saunders-Roe Ltd., Electronics Division, Osborne, East Cowes, Isle of Wight.

Automatic Balancing Three-Channel Strain Gauge Bridge

(Illustrated right)

THE purpose of the Elliott three-channel strain gauge bridge is to provide a means of automatically maintaining the balance of a Wheatstone bridge comprising a number of strain gauge elements. The main features of the equipment are: manual and automatic balancing; maintenance of balance under varying load conditions; three separate channels in one cabinet; interchangeable units, and variable sensitivity.

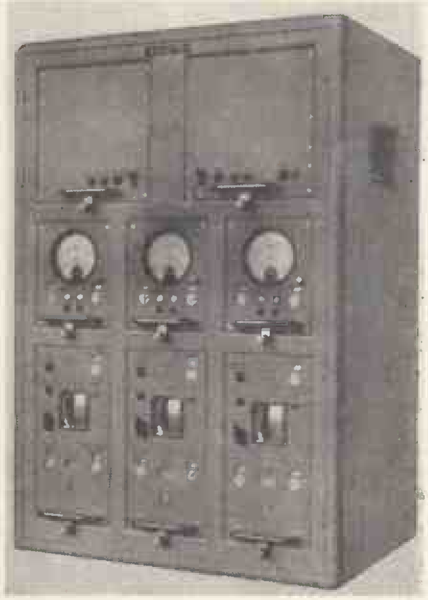
The equipment consists of a cabinet containing an L.T. power pack, H.T. power pack, three amplifier units and three bridge units, the interconnexions being made via a distribution panel by means of Plessey Mk IV plugs and sockets. A small unit external to the cabinet supplies the H.F. excitation to the strain gauge bridges and the reference supply to the discriminator circuits of the amplifiers.

The out-of-balance signal for each bridge is fed into an amplifier, each amplifier consisting of two channels, one feeding the balance meter, and the other feeding the servo motor fields in the bridge units. The meter channel consists of two stages of A.C. amplification followed by a phase-sensitive rectifier circuit, the first stage of A.C. amplification being common to both meters and servo amplifier. The servo amplifier has a total of three stages of A.C. amplification followed by a phase-sensitive rectifier circuit, and a further two stages of D.C. amplification for the operation of the meter fields. Each channel is provided with a gain control, and separate balance controls for the motor and servo channels for initial setting up of the equipment. Provision is made for checking that the quadrature component of the bridge circuit is balanced. The input stability of the amplifier is better than 3×10^{-7} volts.

The bridge, consisting of four strain gauges, may be supplied with 2, 4 or 6 volts H.F. excitation, this being obtained from a transformer mounted on the distribution panel at the rear of the cabinet. This transformer is sufficient to supply up to six bridges, so that two cabinets, i.e. six channels, can be supplied from one H.F. unit, the two cabinets being interconnected via their distribution panels.

The H.F. unit consists of a motor-alternator supplied from the mains via the distribution panel.

The strain gauge bridge is secured to the model support in the wind tunnel. With any movement of the model, a strain will be imposed on the support, thus altering the value of resistance of the gauges, and an out-of-balance signal will be fed into the amplifier. To maintain the bridge balance, current is fed into one of the bridge junctions connected to the amplifier unit, by means of three resistance and one capacitor potentiometer. One of the resistance potentiometers is driven via a gear chain by the servo motor which is supplied by the amplifier unbalance signal until the bridge is balanced. The position of the potentiometer slider is an indication of the amount of current added to the bridge, and is thus a measure of the mechanical load applied to the strain gauge system. The capacitor potentiometer is for the purpose of balancing out the quadrature component of the bridge.



The equipment has a sensitivity which is better than 0·001 per cent strain, and a gauge resistance of 120 ohms. The mains supply is 200-250 volts 50c/s.

This equipment was developed and manufactured for the R.A.E. to their own specification by Elliott Bros. (London) Ltd.

Elliott Bros. (London) Ltd., Century Works, Lewisham, London, S.E.13.

L.E.M. Silvered Mica Capacitor

(Illustrated left centre)

A NEW type of miniature silvered mica capacitor was introduced recently by the London Electrical Manufacturing Co. Ltd. It measures 11 by 6mm, and is available in capacitances of from 20pF to 1 500pF. It is stable, and has a temperature coefficient of 30 parts positive per 1°C plus or minus 10 parts. It is stated that it can be supplied with very close tolerance limits of capacitance and has good characteristics as regards power factor, insulation resistance and stability of capacitance, etc.

London Electrical Manufacturing Co. Ltd., Beavor Lane, London, W.6.

LETTERS TO THE EDITOR

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

Principles of Radio

DEAR SIR,—K. G. Lockyer is not quite fair, surely, in his review of Henney and Richardson's "Principles of Radio" when he criticizes the authors for applying the term Q to a single element such as a coil, and asserts that in fact Q can only be assigned to a resonant circuit. The British Standard "Glossary of Terms Used in Telecommunication" (BS204:1943) specially defines Q in relation to (a) a conducting system, (b) a simple oscillating circuit, and (c) a coil (or capacitor).

Yours faithfully,

M. G. SCROGGIE,
Bromley, Kent.

The reviewer replies:

DEAR SIR,—Mr. Scroggie, in his most pertinent letter raises a point of considerable value to those interested in the education of the electronic engineer. There is no question that practising engineers talk and write of "the Q of a coil" without causing any difficulty or ambiguity. However, the volume under review was not intended for the trained engineer but for the student who, I contend, should be taught to consider Q as a circuit parameter. It would seem to me that Q is best defined in terms of voltage magnification; by a fortunate chance most of the circuit losses generally lie in the inductor, so that the ratio $\omega L/R$ where R is the R.F. coil resistance is readily shown to be effectively equal to Q. Nevertheless, for students, Q should be defined in the first place as a circuit function, and only by derivation as a component property. To define it solely as a component property without any reference to voltage magnification is, I suggest, unsound and liable to cause difficulties in subsequent work. It is on this point that I take issue with the authors.

I am greatly strengthened in my view on this subject by the writings of some of our most competent authors of elementary textbooks. For example, Mr. Scroggie in his "Foundations of Wireless" (fifth edition, 1951) defines Q in the following terms (p.104): "The symbol generally used to denote this voltage magnification is Q", and he states that "at any given frequency, it depends solely on L/R, the ratio of the inductance of the coil to the resistance of the circuit." This association of Q with a circuit I believe to be a wholly correct approach for the student: once this point is firmly secured then, and only then, is a demonstration that Q is effectively the reciprocal of the power factor of the inductor justified.

Yours faithfully,

K. G. LOCKYER,
Streatham Hill,
London, S.W.2.

Pulse Brightening Discrimination

DEAR SIR,—The interesting paper by A. L. Whitwell on "Pulse Brightening Discrimination" has prompted me to pass on to your readers a simplified version of this technique which I have used.

The particular application was continuously recording the input and output voltages of an automatic mains voltage regulator, the response of the regulator to rapid changes of input voltage being of particular interest. The two voltages were rectified and smoothed with chokes and capacitors, fed via a beam switching unit, backing-off battery and D.C. amplifier to the Y plates of the C.R.O. recorder. Brightening pulses at 100 per second were obtained simply by differentiating the "ragged" waveform from one of the rectifiers. Using this method smoothing can be kept to a minimum thereby reducing the circuit time-constant and increasing the response to rapid voltage changes. The 100c/s ripple is eliminated by pulse brightening discrimination.

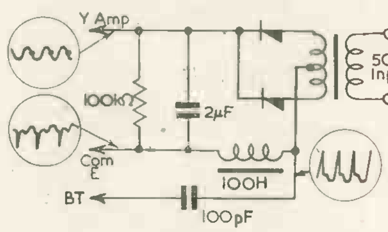


Fig. 1.

The diagram in Fig. 1 shows the circuit arrangement. A negative pulse was used in this particular case as this was necessary to operate the "beam trigger" of the Cossor C.R.O. recorder available.

Yours faithfully,

G. W. MORRIS.
Biophysics Unit.
Crichton Royal,
Dumfries, Scotland.

A Linear Transducer for the Electrical Measurement of Displacement

DEAR SIR,—With reference to the linear transducer described in the September issue, it may be possible to back off the unwanted output before this is rectified. In the case of 6·3 volt 50c/s operation, a suitable voltage could be obtained from a low impedance potential divider connected across the primary supply. For effective working the phase-shift in the transducer must be small, and if this method is to be applied to the measurement of small displacements the residual 90° out-of-phase component must be neutralized.

The backing-off voltage can also be obtained from the slide-wire of a potentiometer recorder, thus forming a recording micrometer. Experiments with a differential transformer used in this way have shown that the sensitivity of the recorder is governed by the residual out-of-phase voltage of the transducer secondary; this residual varied non-linearly with the actual transducer output and it was therefore not possible to achieve exact neutralization and equal sensitivity over the whole working range. Your author's present design may help to overcome this difficulty particularly at low frequencies.

Yours faithfully,

G. BIELSTEIN,
Imperial Institute,
London, S.W.7.

The author replies:

DEAR SIR,—With reference to Mr. Bielstein's letter, the phase difference between the primary and open-circuit secondary voltages of the transducer is approximately 20° at 50c/s. This phase-shift is mainly due to the resistance of the primary winding forming an appreciable part of the primary impedance, and will therefore vary as the coil warms up. If a balancing voltage is to be obtained from the primary supply, it will be necessary either to advance the phase of the voltage by about 20° or to balance out separately the large residual out-of-phase component, and in either case the balance will not be very stable.

A better arrangement is that shown in Fig. 5 of my article, in which the balancing voltage is derived from a third coil. The voltage induced in this balancing coil is of almost exactly the same phase as that induced in the pick-up coil, and a balance good enough for many purposes can be obtained by simply opposing the voltages. Connecting a potentiometer across the balancing coil to obtain a variable balance point will alter the phase of the voltage, but this shift can be kept small and reasonably stable and could be corrected if necessary. The balancing coil need not be wound on a separate former for this purpose, but could be wound over the primary coil.

Mr. Bielstein suggests that there might be a change in the phase of the pick-up coil voltage as the displacement varies. I can think of two possible causes for an effect of this kind: (a) eddy currents in the stampings, and (b) the combined effect of the self-inductance of the pick-up coil (which varies with displacement) and stray capacitances in the coil and its leads. I doubt whether either of these would produce a measurable phase-shift at 50c/s.

The reason I did not suggest balancing the unwanted output as A.C. is that without using multi-grid valves it is difficult to design a phase-sensitive rectifier capable of giving sufficient output to work a graphic recorder, which is also linear, stable and efficient.

Mr. Bielstein's suggestion of using a self-balancing potentiometer is a good one, as it would make the device independent of supply voltage. These instruments are, however, usually comparatively expensive.

Yours faithfully.

M. J. TUCKER,
National Institute of Oceanography,
Teddington, Middlesex.

Notes from the Industry

Sixth Annual R.S.G.B. Amateur Radio Exhibition, November 26-29, 1952. The Sixth Annual Amateur Radio Exhibition organized by the Incorporated Radio Society of Great Britain will be held at the Royal Hotel, Woburn Place, London, W.C.1, from Wednesday, November 26 to Saturday, November 29, 1952. The exhibition will be opened at 12 noon on the 26th by Col. Sir Ian Fraser, C.B.E., M.P., as Past President of the Society.

As in past years the exhibition will be supported by a number of companies who specialize in the provision of valves, apparatus, equipment and publications for the radio amateur. In addition the War Office, Air Ministry and Post Office will be represented.

The sponsoring organization will exhibit apparatus and equipment constructed by members including a "live" amateur transmitting station. The British Amateur Television Club will demonstrate amateur television equipment.

The following have reserved space:—the Air Ministry, Automatic Coil Winder and Electrical Equipment Co., Ltd., Cosmocord, Ltd., E.M.I. Sales and Service, Ltd., Easibind, Ltd., English Electric Co., Ltd., General Electric Co., Ltd., the General Post Office, George Newnes and Co., Ltd., Goodmans Industries, Ltd., Iliffe and Sons, Ltd., Panda Radio Co., Philpotts Metalworks, Ltd., Salford Electrical Instruments, Ltd., Siemens Electric Lamps and Supplies, Ltd., Taylor Electrical Instrument Co., Ltd., the War Office, and Westinghouse Brake and Signal Co., Ltd.

Institute of Radio Engineers' Awards. Dr. John M. Miller, superintendent of Radio Division 1 of the Naval Research Laboratory, Washington, D.C., has been named the recipient of the Institute of Radio Engineers' Medal of Honour for 1953. The Institute gave the award "in recognition of his pioneering contributions to the basic knowledge of electron tube theory, of radio instruments and measurements, and of crystal oscillators."

The 1953 Morris Liebmann Memorial Prize was awarded to John A. Pierce, senior research Fellow at Harvard University. Mr. Pierce is noted for his contributions to the development of the loran system of long range radio navigation and more recently for his conception of the Radux system of long range navigation.

Mr. Frank Gray, research engineer of Bell Telephone Laboratories, Murray Hill, N.J., was awarded the Vladimir K. Zworykin Television Prize Award for 1953. A pioneer in the television field, Mr. Gray early in the 1930's developed principles, the importance of which has only recently been recognized, and which are embodied in the colour television system currently under development by the industry-sponsored National Television System Committee.

Sir Noel Ashbridge joins the Marconi Organization. The English Electric Group of Companies recently announced that Sir Noel Ashbridge, B.Sc., M.I.C.E., M.I.E.E., F.K.C., F.I.R.E., Director of Technical Services, BBC, since 1948, has joined the board of directors of Marconi's Wireless Telegraph Co., Ltd., the Marconi International Marine Communication Co., Ltd., Marconi Instruments, Ltd., and the English Electric Valve Co., Ltd.

Sir Noel, who was knighted in 1935, retired from the BBC in July 1952.

Smithson Research Fellowship. A joint committee consisting of representatives of the Royal Society and the University of Cambridge have appointed Dr. R. J. Eden, M.A., Ph.D., of Cambridge University to be Smithson Research Fellow for four years.

BBC Civil Engineer Retires. The BBC announced recently that Mr. M. T. Tudsbery, C.B.E., M.I.C.E., the Civil Engineer, retired last month under the age limit. Mr. Tudsbery joined the BBC in January, 1926 as the Corporation's first Civil Engineer, and is being retained temporarily as Consulting Civil Engineer to advise the BBC on civil engineering and building matters.

M/V "Pye Dolphin" in the Channel Islands. The M/V "Pye Dolphin", a twin-engined steel hulled craft of 44 feet, 18 tons, owned by Rees Mace Marine, Ltd., recently had an eventful cruise to Guernsey. Despite unfavourable weather trips were made to Herm, Sark and Alderney to carry out routine inspections of the Pye V.H.F. radio telephone multi-channel links which maintain telephone communications with Guernsey. These Pye links are owned by the Guernsey States Telephone Department.

With the co-operation of this Department an experimental V.H.F. system was installed, and the "Pye Dolphin" initiated a ship-to-shore V.H.F. radio telephone service. Local shipowners and other authorities were invited aboard the vessel, which then put to sea, from whence telephone calls were made from the craft to any telephone number in the group of islands over a 20 mile radius, and vice versa.

Errata. On page 403 of the September, 1952 issue of ELECTRONIC ENGINEERING the second reference should refer to a paper entitled "Electronic Servo Simulators," not "Electronic Servo Stimulators." In the article, "The Differential Amplifier with a Useful Modification". by B. F. Davies, also in the September issue an error occurred in the formula below the caption of Fig. 9. This should read:

$$k''' = \frac{2R_L R_C[r_{a1} + R_C(1+\mu)]1/Z}{r_{a1}(R_L+R_C)+(r_{a2}+R_L)[R_C+r_{a1}/(1+\mu)]}$$

Mr. Davies also requests us to point out that his qualification is "Grad.I.E.E."

RECENT BRITISH STANDARDS

British Standard for Electroplated Coatings of Tin. (B.S.1872:1952)

A further standard in the series which is being prepared covering electroplated coatings of various metals has been published recently.

The present document deals with electroplated coatings of tin. It provides for coating of this metal on fabricated articles of iron, steel, copper and copper alloys, and covers five classes of coating according to the use to which the coating is to be put. It also provides details of samplings, finish, solderability, thickness, adhesion and heat treatment, together with the necessary methods of test. The standard costs 2s. 6d.

British Standards for Raw Copper (B.S's 1035-40, 1172-4 and 1861:1952)

The British Standards Institution has issued in one booklet the following ten standards for raw copper:—

B.S.1035 Cathode copper.

B.S.1036 Electrolytic tough pitch high conductivity copper.

B.S.1037 Fire refined tough pitch high conductivity copper.

B.S.1038 99·85 per cent tough pitch copper, conductivity not specified.

B.S.1039 99·75 per cent tough pitch copper, conductivity not specified.

B.S.1040 99·50 per cent tough pitch copper, conductivity not specified.

B.S. 1172 Phosphorus deoxidized non-arsenical copper.

B.S.1173 Tough pitch arsenical copper.

B.S.1174 Phosphorus deoxidized arsenical copper.

B.S.1861 Oxygen-free high conductivity copper.

This includes revised editions of B.S. 1035-40 first issued in 1942, revised editions of B.S.1172-4 published separately in 1944, and a new specification B.S.1861 for oxygen-free high conductivity copper.

Apart from amending the upper limit for phosphorus in B.S.1172 and B.S.1174 only minor changes have been made to both the earlier series but, in some cases the number of significant figures quoted for the limits have been altered so that the correct degree of accuracy is implied. The booklet costs 4s.

British Standard for Rolled Copper Sheet and Strip for General Purposes. (B.S.899:1952)

A revised edition of B.S.899, "Rolled Copper Sheet and Strip for General Purposes," has just been issued. In this revision, which includes provisions for annealed, half hard and hard conditions, the mechanical properties have been modified and elongation requirements have been added, as well as an embrittlement test for deoxidized material. Other minor amendments have been made in order to bring the standard as far as possible into line with the revised edition of B.S.1432, "Copper for Electrical Purposes (Sheet and Strip)" which will be issued shortly. The price of this standard is 2s. 6d.

Copies of these standards may be obtained from the British Standards Institution, Sales Branch, 24 Victoria Street, London, S.W.1.

Meetings this Month

THE BRITISH INSTITUTION OF RADIO ENGINEERS

Date: November 5. Time: 6.30 p.m.
Held at: London School of Hygiene and Tropical Medicine, Keppel Street, London, W.C.1.
Lecture: The Specification and Design of Standardized Units for Electronic Computors.
By: A. D. Booth, D.Sc., Ph.D., F.Inst.P.

Scottish Section

Date: November 6. Time: 7 p.m.
Held at: the Engineering Centre, Sauchiehall Street, Glasgow.
Lecture: The Development of the Radio and Electronics Industry in India.
By: G. D. Clifford, M.Brit.I.R.E.

North-Eastern Section

Date: November 12 Time: 6 p.m.
Held at: The Institution of Mining and Mechanical Engineers, Neville Hall, Westgate Road, Newcastle-upon-Tyne.
Lecture: Radio Counter Measures.
By: H. J. Barton-Chapple, B.Sc., M.Brit.I.R.E.

THE BRITISH SOUND RECORDING ASSOCIATION

Date: November 21. Time: 7 p.m.
Held at: the Royal Society of Arts, John Adam Street, London, W.C.2.
Discussion: Problems of Sound Recording and Reproduction.
(The discussion will be followed by a Brains Trust.)

Manchester Section

Date: November 24. Time: 7.15 p.m.
Held at: the Engineers' Club, Albert Square, Manchester.
Lecture: Some Aspects of Sound on Film Recording and Reproduction.
By: K. Ross.

THE INSTITUTE OF NAVIGATION

Date: November 21. Time: 5 p.m.
Held at: the Royal Geographical Society, 1 Kensington Gore, London, S.W.7.
Lecture: The Vertical Reference in Navigation.
By: W. A. W. Fox and D. Barnett.

THE INSTITUTE OF PHYSICS

Electronics Group

Date: November 11. Time: 5.30 p.m.
Held at: Institute's House, 47 Belgrave Square, London, S.W.1.
Lecture: Information Theory.
By: Dr. P. M. Woodward.

Education Group

Date: November 19. Time: 5.30 p.m.
Held at: 47 Belgrave Square, London, S.W.1.
Lecture: The Teaching of Acoustics.
By: Dr. R. W. B. Stephens, F.Inst.P., Dr. E. G. Richardson, F.Inst.P., and E. Nightingale.
(Joint meeting with the Acoustics Group of the Physical Society.)

Manchester Branch

Date: November 21. Time: 6.45 p.m.
Held at: the Bragg Lecture Theatre, the University of Manchester.
Lecture: Fluorescence.
By: Dr. E. J. Bowen, F.R.S.

Scottish Branch

Date: November 25. Time: 7 p.m.
Held at: the Natural Philosophy Department, University of Glasgow.
Lecture: Television.
By: A. T. Shepherd, A.Inst.P.

THE INSTITUTION OF ELECTRICAL ENGINEERS

(All London meetings, unless otherwise stated, will be held at the Institution, commencing at 5.30 p.m.)
Date: November 6.
Lecture: Telemetering for System Operation.
By: R. H. Dunn, B.Sc., and C. H. Chambers.
Date: November 13.
Lecture: A 150kV X-ray Equipment for the Radiography of Circumferential Welds in Gas-Turbine Rotors
By: F. W. Waterton.

Informal Meeting

Date: November 17.
Discussion: The Field of Application of Metal Rectifiers.
Opened by: S. A. Stevens, B.Sc.(Eng.).

Radio Section

Date: November 12.
Lecture: Radio Telemetering.
By: E. D. Whitehead, M.B.E., B.Sc., and J. Walsh, B.Sc.
Date: November 18.
Lecture: Harmonic Response Testing Apparatus for Linear Systems.
By: D. O. Burns, B.Sc.(Eng.), and C. W. Cooper, B.Sc.(Eng.).
Lecture: A Simple Connexion Between Closed-Loop Transient Response and Open-Loop Frequency Response.
By: J. C. West, B.Sc., and J. Potts, B.Sc.
(Joint Meeting with the Measurements Section.)
Date: November 24.
Informal Lecture: Recent Progress in Radar Duplexers, with special reference to Gas-Discharge Tubes.
By: P. O. Hawkins.

Measurements Section

Date: November 4.
Discussion: Circuit Applications of Cold-Cathode Trigger Tubes.
Opened by: K. Kandiah.
Date: November 18.
(See Radio Section for Joint Meeting.)

East Midland Centre

Date: November 4. Time: 6.30 p.m.
Held at: Loughborough College.
Lecture: Inhibited Transformer Oil.
By: W. R. Stoker, B.Sc.(Eng.), and C. N. Thompson, B.Sc.
Lecture: Stability of Oil in Transformers.
By: P. W. L. Gossling, B.Sc., and L. H. Welch, B.Sc.(Eng.).
Date: November 18. Time: 6.30 p.m.
Held at: the Electricity Service Centre, Derby.
Discussion: The Problems associated with the Application of Electronics in Heavy Industry.
Opened by: H. E. Knight.

Cambridge Radio Group

Date: November 11. Time: 8.15 p.m.
Held at: The Cavendish Laboratory, Cambridge.
Address by the Chairman of the Radio Section.

North-Eastern Centre

Date: November 10. Time: 6.15 p.m.
Held at: the Neville Hall, Westgate Road, Newcastle-on-Tyne.
Lecture: Voltage Transformers and Current Transformers associated with Switchgear.
By: W. Gray and A. Wright, B.Sc.
(Joint Meeting with the North-Eastern Centre Radio and Measurements Group.)

North-Eastern Radio and Measurements Group

Date: November 3. Time: 6.15 p.m.
Held at: King's College, Newcastle-on-Tyne.
Informal Lecture: The General Principles of Digital Computors and their Applications.
By: F. C. Williams, O.B.E., D.Sc., D.Phil., F.R.S.
Date: November 10.
(See North-Eastern Centre for Joint Meeting.)
Date: November 17. Time: 6.15 p.m.
Held at: King's College, Newcastle-on-Tyne.
Lecture: Microwave Radio Links.
By: A. H. Starr, M.A., Ph.D., and T. H. Walker, B.Sc.Tech.

North-Western Measurements Group

Date: November 25. Time: 6.15 p.m.
Held at: the Engineer's Club, Albert Square, Manchester.
Lecture: Voltage Transformers and Current Transformers associated with Switchgear.
By: W. Gray and A. Wright, B.Sc.

North-Western Radio Group

Date: November 26. Time: 6.30 p.m.
Held at: the Engineer's Club, Albert Square, Manchester.
Lecture: Radio Telemetering.
By: E. D. Whitehead, M.B.E., B.Sc., and J. Walsh, B.Sc.

Northern Ireland Centre

Date: November 11. Time: 6.45 p.m.
Held at: the Presbyterian Hostel, Howard Street, Belfast.
Lecture: Some Recent Developments in Phototelegraphy and Facsimile Transmission.
By: J. Bell, M.Sc., J. A. B. Davidson, M.A., and E. T. A. Phillips.

North Scotland Sub-Centre

Date: November 12. Time: 7.30 p.m.
Held at: Caledonian Hotel, Aberdeen.
Lecture: Technical Colleges and Education for the Electrical Industry.
By: H. L. Haslegrave, M.A., Ph.D., M.Sc.(Eng.).
Date: November 13. Time: 7 p.m.
Held at: the Royal Hotel, Dundee.
Lecture: as at Aberdeen.

South Midland Centre

Date: November 7. Time: 7 p.m.
Held at: the Electrical Engineering Department, College of Technology, Birmingham.
Lecture: Teaching of Television Servicing.
By: R. G. Moseley.
(Education Discussion Circle Joint Meeting with the South Midland Radio Group.)

South Midland Radio Group

Date: November 24. Time: 6 p.m.
Held at: the James Watt Memorial Institute, Great Charles Street, Birmingham.
Lecture: Radio Astronomy.
By: K. D. Machin, M.A.

Southern Centre

Date: November 13. Time: 7.30 p.m.
Held at: R.A.E. College, Farnborough.
Informal Lecture: Radio Controlled Models.
By: P. A. Cummins.

Irish Branch

Date: November 20. Time: 6 p.m.
Held at: Trinity College, Dublin.
Lecture: Condensers and Power Factor Improvement.
By: J. J. Morrissey, M.A., M.E.

District Meetings

Date: November 3. Time: 6.30 p.m.
Held at: the Crown and Anchor Hotel, Ipswich.
Lecture: The Determination of Time and Frequency.
By: H. M. Smith, B.Sc.

THE INSTITUTION OF ELECTRONICS

North-Western Branch

Date: November 28. Time: 7 p.m.
Held at: Reynolds Hall, College of Technology, Manchester.
Lecture: Discharge Mechanisms in Cold-Cathode Valves.
By: R. W. Murray, M.A.

THE INSTITUTION OF POST OFFICE ELECTRICAL ENGINEERS

Date: November 11. Time: 5 p.m.
Held at: Institution of Electrical Engineers, Savoy Place, London, W.C.2.
Lecture: Subscriber Trunk Dialling.
By: D. A. Barron, M.Sc.(Eng.), A.M.I.E.E.

Informal Meeting

Date: November 26. Time: 5 p.m.
Held at: Conference Room, 4th Floor, Waterloo Bridge House, London. S.E.1.
Lecture: Mechanical Aids.
By: G. A. Probert, A.M.I.E.E.

THE PHYSICAL SOCIETY

Date: November 28. Time: 5 p.m.
Held at: The Physical Society, London, S.W.7.
Lecture: Some Topics Concerning the Production and Application of Nuclear Emulsions.
By: C. Waller.
Lecture: Paramagnetic Resonance at Low Temperatures.
By: Dr. B. Bleaney.

Acoustics Group

Date: November 19. Time: 5.30 p.m.
Held at: the Institute of Physics, 47 Belgrave Square, London, S.W.1.
Lecture: The Teaching of Acoustics.
By: Dr. R. W. B. Stephens, F.Inst.P., Dr. E. G. Richardson, F.Inst.P., and E. Nightingale.
(Joint Meeting with the Institute of Physics Education Group.)

PRESENTATION OF TECHNICAL INFORMATION DISCUSSION GROUP

Date: November 19. Time: 6 p.m.
Held at: University College, Gower Street, London, W.C.1.
Lecture: Production of Technical Instruction Manuals.
By: J. W. Godfrey.

RADIO SOCIETY OF GREAT BRITAIN

Date: November 21. Time: 6.30 p.m.
Held at: The Institution of Electrical Engineers, Savoy Place. London, W.C.2.
Lecture: The Skybeam Propagation Problem.
By: P. H. Sollom, B.Sc., A.C.G.I.

THE TELEVISION SOCIETY

Date: November 13. Time: 7 p.m.
Held at: 164 Shaftesbury Avenue, London, W.C.2.
Lecture: Component Reliability in Television Receivers.
By: G. D. Reynolds, M.Sc., M.I.E.E., A.R.I.C.
Date: November 28. Time: 7 p.m.
Held at: 164 Shaftesbury Avenue, London, W.C.2.
Lecture: The Development of High Quality Front Projection Receivers.
By: P. D. Saw.

ELECTRONICS IN INDUSTRY

The second supplement to Electronic Engineering dealing with recent applications of electronics to control of and measurement in manufacturing processes in industry.

CONTENTS

THE first supplement on the subject of electronics in industry was published in the April issue of ELECTRONIC ENGINEERING and was designed to show what had already been done to raise productivity by the application of the new methods and techniques provided by electronics for research and for manufacturing processes. We took as our main theme the contribution electronics has made to existing industrial processes in the more accurate control of the process through its various stages. It was shown that many continuous manufacturing processes requiring frequent adjustment of speed, temperature, pressure, etc., readily lent themselves to electronic control and often considerable economy of man-power could be achieved.

In some of the more established industrial processes the older methods are still reliable and economic and while electronic ways of performing the same functions have been devised, economic considerations sometimes prevent their large scale adoption.

In this second supplement we are proposing to continue the theme but at the same time giving emphasis to the way in which electronics is proving of assistance in the industrial research and development laboratories and how, as a result, some old problems are now reaching solution. One of these is vibration, which as a destructive force has long been the bane of civil and mechanical engineers. In the past many types of structures have failed due to vibration or stress fatigue and the measuring equipment at the disposal of the designer has provided little knowledge of the stresses set up under dynamic loads. To an otherwise satisfactory design for steady loads, due allowance for vibratory loads, in the form of a factor of safety (more correctly termed a factor of ignorance), had to be made based largely on trial and error.

This is now largely a matter of the past for with the resistance strain gauge, the transducer and the cathode-ray oscillograph, measurements can be made of the stresses set up in rotating parts and in structural elements otherwise inaccessible and at frequencies which are beyond the scope of mechanical and optical instruments.

The aircraft industry was one of the first to make an intensive study of vibration and stress fatigue and it is true to say that the highly successful performance of aircraft such as the Comet could not have been achieved without this essential preliminary investigation.

Thus already electronics in its present state is proving an indispensable aid for research and development, but even more promising are the possibilities of the newer science of nucleonics.

The successful explosion of the first British-made atomic bomb at the Monte Bello Islands has tended to overshadow the efforts this country is making in the more peaceful uses of atomic energy. Security reasons obviously prevent any detailed official announcements regarding the bomb, but not all the activities of Harwell and elsewhere are being directed towards the race for bigger and better bombs. Already Great Britain is the world's largest exporter of radioactive isotopes which are proving of such value in medical research, and the future industrial applications are likely to be no less valuable.

The industrial applications of nucleonics are only beginning and in many cases are opening up entirely new methods of investigation. One attractive example which has come to our notice recently is a method for determining wear in internal combustion engines. By making radioactive the parts of the engine subject to wear, the lubricating oil itself becomes radioactive as the surfaces wear away, and by determining the "contamination" of the lubricating oil the degree of wear can be ascertained without having to dismantle the engine.

Aircraft Vibration Research

By D. M. Corke*

IN this country the need for large scale investigation of aircraft vibration problems can be said to have started with the expansion of the aircraft industry just before the last war. Before this, vibration and fatigue problems had hardly begun to make themselves felt, except perhaps in aircraft engines; and such work as had been done was carried out largely with mechanical and optical equipment.

The decision of de Havilland Propellers Ltd., at that time a Division of the de Havilland Aircraft Company, to embark upon the production, under licence from Hamilton Standard Propellers, of metal-bladed variable-pitch propellers in 1935-36, led to the formation, on American advice, of a small group to study vibration problems in relation to British applications of the new propellers. The equipment available for vibration research was found to be practically non-existent in England, and the new department had to design and develop its own apparatus from the start. During the war years, the many new aircraft applications led to a rapid increase in the size and scope of the department, which found itself being asked to carry out tests on aircraft engines and airframes, as well as a number of investigations in other industries. On propellers themselves, it was found possible as a result of vibration measurement and analysis, to bring about a 50 per cent reduction in weight per horse-power absorbed. The research equipment developed for internal use proved to be so effective that numerous enquiries for supply led to the decision to manufacture for sale at the end of the war, and a special Division of de Havilland Propellers Ltd. has been formed for this purpose.

The rapid expansion, after the war, of the civil aircraft transport industry, with aircraft flying hours mounting into thousands, has raised many problems of structural and component fatigue which have led to a considerable re-orientation of the department's activities, and a great deal of work has been done on methods of increasing the fatigue resistance of components and materials. It is now clear that vibration and fatigue will be among the major limiting factors in all future aircraft designs. These limitations, and the need for vibration analysis and stress measurement in any other branch of engineering where the demand for improved performance by increasing motive power and reducing structural weight means that materials must be specified critically and used to the limit of their capacity, make it certain that vibration research is going to be of increasing importance in the near future.

For the purposes of this article, vibration research may be split up into three main groups of activity: the measurement and recording of vibration stresses and amplitudes in the field under normal operating conditions; the investigation of modes of vibration of structures and components under artificially produced excitation; and fatigue testing under controlled conditions in the laboratory. These will be dealt with in separate sections below; with descriptions of the relevant apparatus and examples of typical installations.

Measurement and Recording

Vibration makes itself felt in two ways; unpleasant physiological sensations, "pins and needles", and noise; and premature, sometimes disastrous, failures of components and structures. The physiological effects must be attended to, particularly where fare-paying passengers are concerned, although the Armed Forces are beginning to realize the serious effects of excessive noise and discomfort upon personnel in situations where alertness and judgment are required. Noise level measurements have been made in flight, using a Standard Telephones & Cables' Objective Noise Meter. This, in conjunction with octave filters, suitably weighted, can be used to measure sound intensity or loudness levels in each band throughout the sound spectrum.

For measurement of vibration amplitudes there are two basic types of instrument measuring relatively to either a seismic mass or to another selected fixed station. The most satisfactory seismic type so far developed uses the moving-coil principle, inverted in that the coil and its suspension arm form the seismic element, and the magnet and the pick-up case move with the vibrating body. The seismic mass being relatively small means that light control springs and simple damping may be used, the latter being achieved by using a metal coil former built up by silver plating, and the pick-up output being proportional to velocity of move-

* *De Havilland Propellers, Ltd.*

ment. The output can be integrated by a resistance-capacitance filter to give an amplitude signal, or differentiated to give acceleration if required. For torsional oscillations of shafts a similar type of instrument is used, except that the magnet now forms part of the flywheel which acts as a seismic element, and the coil is attached to the shaft.

Large amplitudes at low frequencies are difficult to handle with moving-coil type instruments, and for these, where amplitudes of ±1in. or more are covered, a non-seismic type pick-up consisting of a loop of thin duralumin strip is used. One point of the circumference of the loop is attached to the base of the instrument, and the point diametrically opposite fastened to a drive rod working in guides and attached to the point of measurement. To the loop are cemented four resistance strain gauges, connected in a bridge circuit and polarized by a battery contained in the base of the instrument. These pick-ups are used for mode investigations in airframes and similar large structures, the body of the pick-up being attached to a convenient stationary point. One of these may be seen in the top right-hand corner of Fig. 1.

The resistance strain gauge may fairly be called one of the principal and most generally useful tools of the

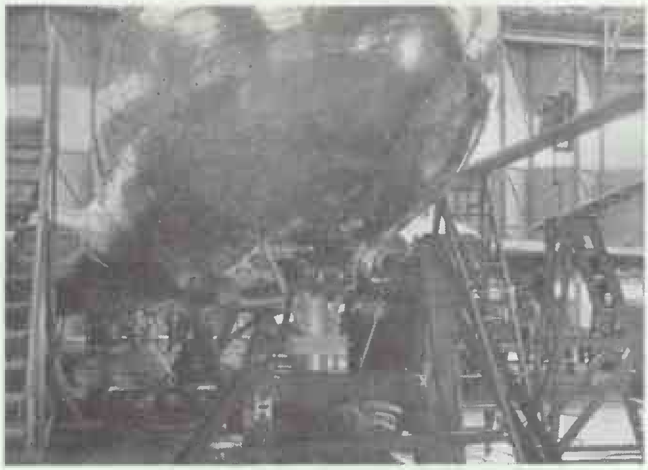


Fig. 1. Resonance test on a Comet aircraft showing large vibrator and vibrator pick-up

vibration engineer. It enables him to measure with considerable accuracy the mean mechanical strain over a comparatively short length of material, and collectively can be used to give a very great deal of information about the stress distribution under operating conditions in vital components. These gauges have played a vital part in the investigation and prevention of the disastrous failures by metallic fatigue, which, as mentioned above, make up the more important part of the vibration engineer's task.

A great number of different types of resistance strain gauge have been developed by various organizations. The principle was first described nearly 100 years ago by Kelvin, who discovered that the changes in resistance of a wire stretched within its elastic limit varied in direct proportion to the changes in applied strain. Early gauges used thin slips of solid carbon composition, or films of sprayed carbon on insulating backing, but all modern types use thin high resistivity wire wound in a zig-zag manner on a paper base to give a high resistance in as small a compass as possible. A number of other types, using wire interwoven with fabric into a ribbon; thin vacuum-deposited metal films, and photographically produced or etched zig-zag strips have also been produced, and it is difficult to foretell what line future developments are likely to take. A big potential demand exists, for instance, for gauges that will withstand prolonged vibration under fatigue test conditions, and also for gauges that will operate satisfactorily at high temperatures for gas turbine and rocket work.

In use, the strain gauge is cemented intimately to the component under test, with its major axis in the direction of the estimated principal strain. Elastic deformation of the component in operation produces corresponding changes in the length of the gauge wire, which, in turn, produce proportional changes in the resistance of the wire element. By connecting the gauge into a bridge network the resistance changes can be taken out as unbalance voltages which can be passed into the measuring and recording equipment. These gauges may be made in a variety of sizes and configurations to suit different applications, and may be arranged to measure longitudinal and torsional strains and to investigate the direction of principal stresses in sheets and panels. To measure steady stresses special types of multi-way Wheatstone bridges with automatic channel switching are used, the balance being read off in terms of percentage change of resistance of each gauge. A notable application of these was the measurement of the steady stress distribution under full load conditions in the mock-up Comet wing main spar, and Fig. 2 shows a number of strain gauges in various stages of installation and waterproofing on the spar.

To record vibration stresses, standard type A.C. coupled

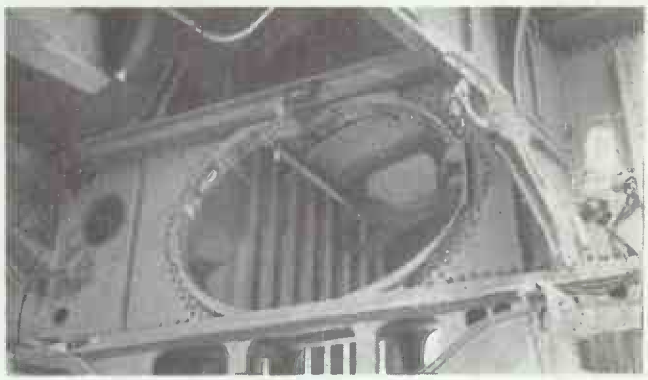


Fig. 2. Comet wing mainspar in test rig with strain gauges fitted for steady stress investigation

amplifiers are used with D.C. polarization on the gauges, and for steady or slowly fluctuating stresses such as wing spar measurements in flight, with the same amplifiers A.C. polarization at 400c/s is resorted to.

For measurements in rotating members, such as propellers and crankshafts, the polarizing currents are fed to the strain gauges through stainless steel slip rings with silver carbon brushes. A typical propeller installation is shown in Fig. 3 where two four-bladed contra-rotating propellers fully strain gauged are mounted on a Bristol Coupled Proteus turbine engine. The front slip ring unit with its signal cable can be seen on the hub.

For stress recording it is necessary to use amplifiers, and these must be designed with special care, as uniform frequency response, minimum harmonic distortion, phase shift, and background noise level with maximum stability are essential to ensure that a faithful copy of the input signal is presented to the recorder. This must be associated with low power consumption, as it is necessary for use in aircraft to keep size down to the minimum, and the temperature rise must not be unreasonably high. At a matter of policy, these compact amplifiers are now being used for most tests involving amplitude or stress recording at frequencies up to 1000c/s, so that the equipment is at all times easily transportable. The amplifiers are made up in banks of six with a common power pack; each unit being individually screened and easily detachable for servicing. Each amplifier consists of a single triode valve input stage, this vaive mounted anti-microphonically on rubber is followed by two push-pull stages with a Mumetal cored output transformer. Push-pull stages, as well as reducing harmonic distortion, avoid the use of the very bulky decoupling capacitors that would be necessary to achieve linearity of response down to 5c/s. Feedback is taken from the output transformer secondary back to the first stage to give a large reduction of overall gain and minimize the effect of supply fluctuations. American metal cased H.F. pentodes are used for the first two stages with B7G base miniature pentodes strapped as triodes for the output stage, but it is likely that new British miniature valves now under development will be used to replace the American type shortly as they promise to be less microphonic and to have a lower intrinsic hum level.

The monitor units used with these amplifiers are again six channel units using RCA.913 one inch diameter oscilloscope tubes, with built-in voltage amplifier stages for driving the deflector plates, each unit containing its own time base and power pack. The monitor tubes are used for examination of the signal waveform to determine whether satisfactory operation of the equipment is being achieved and to set the output signals to suitable levels, by means of the input unit attenuators, for recording in the camera. This last contains conventional d'Arsonval type high frequency galvanometers with a flat characteristic up to 800c/s and records twelve channels on six inch wide paper in 130 foot lengths, or six channels on three inch wide paper. Timing and tachometer marking spots are put on from miniature gas discharge tubes, and the footage of film expended is shown automatically on indicators mounted on the monitor units. Various film speeds up to six feet per second can be obtained to suit the requirements of the test in progress. For bench work the various units can be run straight off 240V 50c/s with batteries for the valve heater supplies, while for flight work rotary invertors are used to supply the necessary A.C. A view of a typical installation in the Armstrong Whitworth Apollo aircraft is shown in Fig. 4, with the input and monitor units in the foreground and the camera, amplifiers and batteries at the back. These amplifiers will give a full width trace on the camera with standard strain gauges at a stress of ±500 p.s.i. in dural, or ±1 500 p.s.i. in steel at unity attenuation; and ±16 000 p.s.i. and 50 000 p.s.i. respectively at maximum attenuation. The total weight of the twelve channel portable equipment, without batteries, is 310lb and it may be conveniently transported in the back of a car.

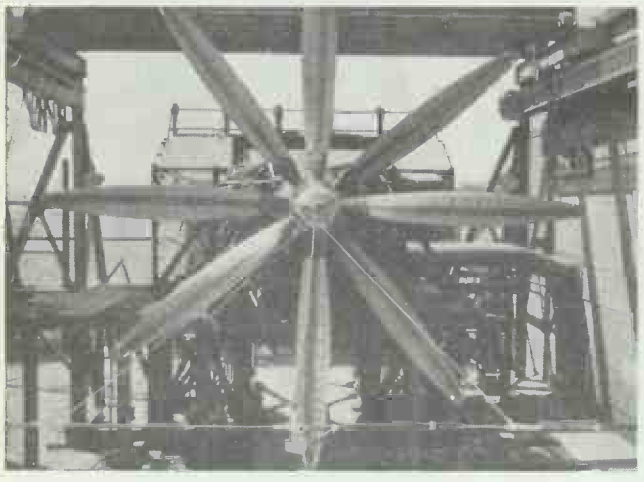


Fig. 3. Bristol Coupled Proteus engine for Princess flying-boat fitted with contra-rotating propellers fully strain-gauged

For high frequency recording, as required for strain gauge work on gas turbines, where frequencies up to 5000c/s are common, a modified version of the above amplifier is used, working directly into photographic $1\frac{1}{4}$in. oscillograph tubes. A high speed six channel camera has been built to record directly from these, giving speeds up to 20 feet per second with 60mm wide film. To start and stop film at such velocities without tearing the film or wasting recording space requires very careful attention to take-up drives in order to prevent over-running and loop formation, but the advantages of the continuous film camera over the conventional drum type for test bed work are so marked as to make the development well worth while. In connexion with this work in gas turbines, the use of conventional types of slip rings has been successful, and it has been found that by using air cooling jets on the brush carriers perfectly satisfactory recordings can be obtained from strain gauges on rotors running at speeds up to 11 000 R.P.M.

Telemetering of Signals

For some types of aircraft tests, particularly in high speed single seater machines, it was thought that it would be advantageous to use a radio telemetering system for multi-channel vibration recording, as not only would it relieve the pilot of attending to the rather specialized requirements of operating the recording gear, often under high acceleration manoeuvring conditions, but would also ensure the survival of the records in the possible event of trouble with the aircraft. The variable width pulse method is used, operating on a carrier frequency of 240Mc/s. A train of successive pulses, spaced 100μsec apart are transmitted, each pulse referring to a different vibration signal channel, and the width of each proportional to the instantaneous amplitude of the signal in question. Conventional gating circuits are used for scanning each channel in succession, and the corresponding circuits in the receiver are synchronized with those in the transmitter. Each receiver channel accordingly accepts a series of variable width pulses which, when fed into a low-pass filter, are resolved into a train of oscillations identical with the original vibration signal, which are fed into the standard recording equipment. A considerable amount of work remains to be done to reduce the bulk of the equipment and to obviate variable reflexion effects due to the motion of the aircraft relative to the ground station.

Fig. 4. Twelve-channel portable vibration recording gear installed on an Armstrong Whitworth Apollo aircraft

Reverting to steady stress measurements on airframes and other structures, as in the type of strain gauge test shown in Fig. 2, a 25-channel Wheatstone bridge arrangement is used, with the common measuring arm calibrated in percentage change of resistance. This means that the bridge reading is independent of the type and initial resistance value of the gauges used, and enables rapid translation of the readings obtained into terms of stress to be made. A uniselector switch is built into the bridge unit, and each strain gauge is switched in in succession and balanced initially under no-load conditions with the common measuring arm of the bridge at zero. Temperature compensating gauges are used in the adjacent arm of each bridge circuit to eliminate the effect of differential thermal expansion effects between the gauges and the components to which they are cemented. As the load is applied, each gauge is switched in once more and the change in resistance read off at balance. For tests of this type the number of gauges used runs into many hundreds, and as many as eight bridge units have been used simultaneously.

Investigation of Modes of Vibration

In the case of complicated components and structures it is difficult to calculate the resonant frequencies and modes of vibration, and it is important to investigate these in the laboratory. Electrical methods are by far the most flexible for this, and for excitation purposes, moving-coil type transducers have been found by far the most satisfactory. These need no explanation as they are identical in principle, if not in scale, with those used to drive the cones of loudspeakers. The largest used has a moving coil 20 inches in diameter and develops a peak thrust of 1700lb.

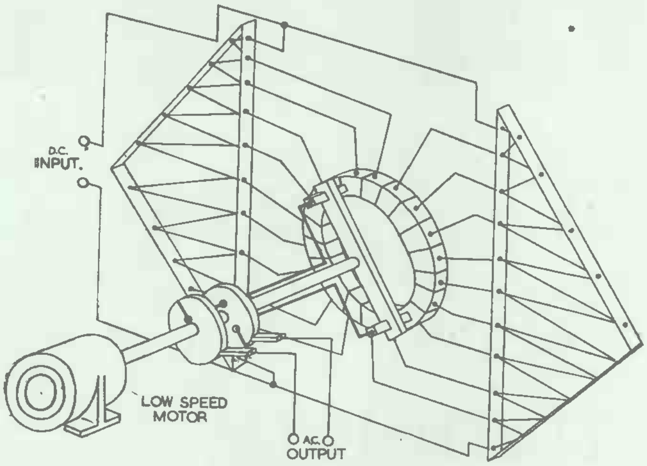


Fig. 5. Very low-frequency generator circuit

These large types have electrically energized field magnets and require air blast cooling. The moving coil is connected by means of a drive rod to the structure to be investigated and alternating current of the appropriate frequency fed into it. For audio frequency work, large amplifiers are used, specially designed to give full power down to the lowest possible frequency, usually about 10c/s. This involves very careful attention to the design of de-coupling circuits and output transformer. For investigations on airframes, where resonance checks are now a standard requirement of the airworthiness acceptance tests, even lower frequencies are required to excite fundamental wing modes, etc. For this, a generator based on the circuit shown in Fig. 5 has been built, consisting of a network of large resistors of graduated value. The tappings are brought out to the segments of a radial commutator as shown. The steps are approximately sinusoidal in value, so that rotation of the brushes at constant velocity gives rise to a substantially sinusoidal change in voltage across a constant load between the brushes, the frequency depending on the rotational speed. It was realised that this type of generator would be only about 20 per cent efficient because of the losses in the fixed resistors, but this would be comparable with those in a large amplifier of equivalent output. The generator in use is designed to deliver 2kW into the vibrators used, and is excited by a 300V D.C. generator. It has no theoretical lower limit of frequency, but is arranged to operate between 1 and 50c/s. (It was estimated that the output transformer for an electronic amplifier of similar output would weigh about 2 tons.) For output adjustment, a constant impedance attenuator is used, in order to ensure that the generator operates under constant load conditions, so that the waveform is kept truly sinusoidal. For airframe tests, the loop type pick-ups described above are used, a large number being attached to selected points along the wings and fuselage. The outputs from these are monitored by direct measurement on the oscilloscope screens in order to get the amplitude distribution. Coupled to the brush carrier shaft of the low-frequency generator is a small three-phase generator. The output from this is fed into a similar three-phase stator which is fitted over the neck of the phasing unit oscilloscope tube. The rotating field produced swings the spot in a circular path on the screen at the generator frequency. The spot is suppressed except when the input signal, which may be taken from any one of the pick-ups in turn, goes through zero in the positive-going direction. A brightening pulse is then produced which shows the instantaneous position of the spot on the long persistence screen of the phasing oscilloscope. The phase angle relative to the generator can then be read off the protractor type graticule fitted. By using uniselector switching, a rapid survey can be made of 24 pick-up points, amplitudes and phase readings being taken off each in turn from the screens of the two units. Using this equipment, all the major modes of vibration of an aircraft can be excited and plotted in a few days. Fig. 1 shows a view of the Comet with the vibrator attached to the nose wheel leg and a loop pick-up measuring lateral nose movements.

An alternative type of low frequency generator uses a standard D.C. generator driven by an induction motor. The generator bushes are rotated about the commutator axis at the required speed, and provided that the field flux distribution is satisfactory, a sinusoidal voltage can be picked up. This type of generator is considerably more efficient and has a much lower internal impedance, so that load matching is much less critical.

Another investigation of this type is the measurement of the vibration characteristics of a structure in terms of mechanical impedance. This is done by measuring the driving force at the point of attachment of the vibrator by strain gauge methods and the amplitude at the same point with a pick-up. The ratio of force/amplitude at each frequency is called the impedance, and a plot of this against frequency yields a curve very similar to the electrical impedance curve for a complex filter network or a transmission line, with alternate zeros and infinites. The mechanical parameter is not strictly analogous to electrical impedance and should more properly be called "effective stiffness", but its properties are very similar. A common test is to measure the torsional mechanical impedance of a propeller by this means and by matching this against the corresponding curve for the engine to determine the modes and frequencies of vibration of the combination when coupled together. This type of test is also being carried out on aircraft control systems to determine the characteristics of the power control mechanisms.

Fatigue Testing

It is now well known that most substances will fail in an apparently brittle manner under vibratory loading at stress levels far below the nominal ultimate strength value if a sufficient number of stress cycles are applied. This number may, in the case of non-ferrous materials, run into hundreds of millions of cycles. The failures give no warning at all of their onset, and metallurgical examination of the material just before failure will give no indication at all of its imminence. It is noteworthy, as well, that the nominal fatigue strength of the material, usually measured on small highly polished specimens, gives no clue as to the strength of a large component made of that material. It is necessary, therefore, to establish fatigue strength figures more or less statistically by testing full sized components in their normal finished condition. Here resonance, the bugbear of the vibration engineer, is turned to use by running the test specimens under resonant conditions and using the increase in stresses and reduction of power required to advantage. Various methods are used to keep rigs running in resonance, and one of the most elegant is that used for blade testing. A view of three of these rigs is shown in Fig. 6 with the latest type hollow steel blades installed for test. Each blade is suspended vertically and excited at the root end by a large moving-coil vibrator at the top of the rig. At the lower end of the blade is placed a microphone which can pick up the sound waves set up by the vibration. The signal from this is fed, through a pre-amplifier, into the power amplifier which supplies the vibrator, thus completing the electro-mechanical loop. The phase-shift is adjusted in the pre-amplifier until the system becomes regenerative at the particular natural frequency that it is desired to excite in the specimen, and the rig will then start up and continue running in that mode automatically. Stresses are measured in the usual manner by strain gauges cemented to the blade surface and the stress level set by adjusting the power fed into the vibrator. The rig can then be left to run with periodic stress monitoring until failure occurs. The monitoring is carried out on a large screen oscilloscope with a variable gain amplifier. The strain gauge output voltages are compared against fiducial marks on the oscilloscope screen with calibration signals derived from the 50c/s supply. The strain gauge output can thereby be read off in millivolts and translated directly into stress figures, thus enabling very rapid stress distribution surveys and checks to be carried out on each rig periodically. The gauges and their lead wires can be clearly seen in the figure.

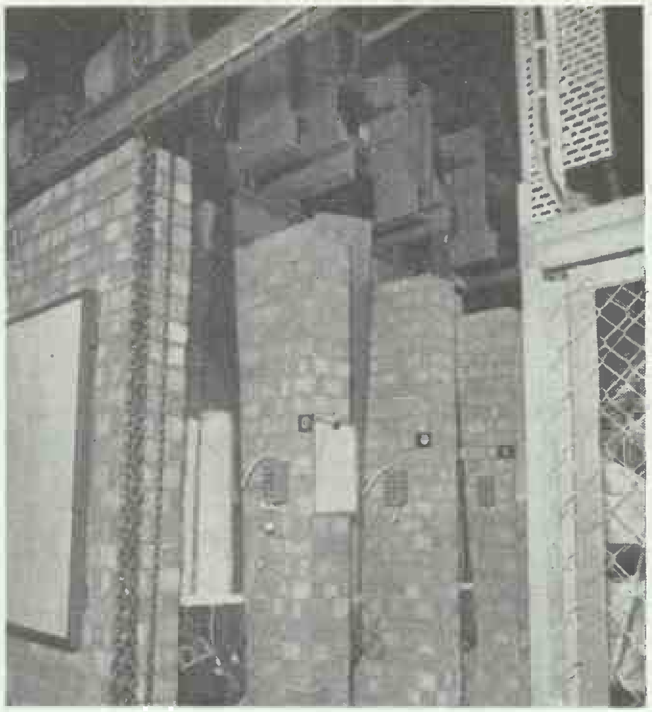


Fig. 6. Hollow steel propeller blades in fatigue testing

Conclusion

It will be realized that electronic applications have an immense scope in vibration engineering, and that it has only been possible to touch on the fringes of the subject in this article. The importance of vibration studies is increasing in many fields outside the aircraft industry, and this will play its part in advancing the ever broadening front of electronics in the industrial field of today.

The author wishes to thank de Havilland Propellers Ltd. for permission to publish this paper and the following companies for permission to publish their photographs: de Havilland Aircraft Co.; Sir W. B. Armstrong Whitworth Aircraft Ltd.; the Bristol Aeroplane Co.

ULTRASONIC TECHNIQUES in the Rubber Industry

By R. G. Patton* and P. Hatfield*, M.Sc., A.Inst.P.

The two main applications of ultrasonic techniques in the rubber industry are the detection of internal air films in rubber products, and the measurement of rubber thickness when only one surface is available. Because of the high absorption of ultrasonic waves in rubber, low frequency (50-250kc/s) methods using continuous or noise modulated ultrasonic waves have been developed to solve these two problems. High-powered ultrasonic waves have been used, on a laboratory scale, but so far no general industrial use has been made of them. It is possible that some of these laboratory methods may in the future be applied in industry. Some of the problems investigated have been the de-gassing of liquids and the aqueous dispersion of solids.

THE basic physical factor on which all ultrasonic methods have been based is that there is 100 per cent reflexion of ultrasonic waves at a solid/air boundary. The detection of internal air films in metals by ultrasonic pulse systems is well established. The fault area to be detected in metals is usually very small and an ultrasonic frequency above 350kc/s is used, since the wavelength must be smaller than the fault area. Owing to the setting up of a stationary wave system at high ultrasonic frequencies, it is not practicable to use continuous waves. The early systems for detecting air films in metals attempted to use continuous ultrasonic waves, but results were not satisfactory and so pulse methods were developed.

Because of the high absorption of the ultrasonic waves in a tyre, and also the scattering caused by the fabric of the tyre, it is necessary to use low ultrasonic frequencies. At the low ultrasonic frequencies a wide beam is emitted and true stationary waves are not set up, consequently continuous waves can be used.

The main method which has been adopted to detect internal films in tyres is shown schematically in Fig. 1. An

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electrical oscillator feeds a transmitting quartz crystal placed in the well of the tyre, which is filled with water. The frequency is about 50kc/s and an approximately 120° divergent continuous wave ultrasonic beam is transmitted from the quartz crystal via a rubber nose pad into the water and passes easily through the tyre. A lower frequency would give a wider beam, but a lower resolving power in detecting internal faults. Six identical receiving quartz crystals placed outside the tyre, in water, convert any received ultrasonic waves into small amplitude electric waves, which are amplified and shown as meter readings by six separate meters. If an air film is present in the tyre, as shown in Fig. 1, just above No. 2 receiving crystal, then no ultrasonic waves are detected by this crystal because they are completely reflected at the rubber/air interface. No signal is received by No. 2 amplifier and the meter reads zero.

The minimum fault area which can easily be detected is about $\frac{3}{8}$in. by $\frac{3}{8}$in. because ultrasonic waves at 50kc/s can easily pass round faults smaller than this area. In order to test a tyre, it is essential that no air bubbles adhere to the surface and to ensure this, the tyre is rotated several

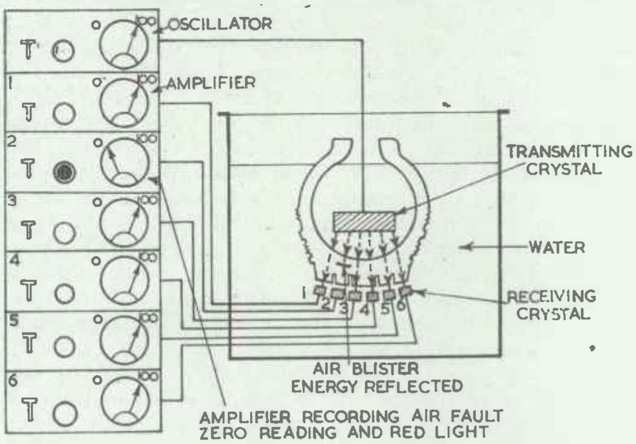

Fig. 1. Schematic diagram of apparatus for detecting air films in tyres

times in the water at relatively high speed (10 R.P.M.). After wetting the tyre thoroughly, it is then rotated slowly and in one revolution 5in. of the tyre section is examined. To test the remaining arc of tyre section, the receiving crystals and transmitting crystal must be removed to a fresh position, and the tyre again rotated. By moving the crystals several times, depending on the size, a tyre can be completely examined in a relatively short time.

Large fault areas 1in. by 1in. of negligible thickness give 100 per cent drop in signal strength. Smaller faults give correspondingly smaller drops in signal strength. Arrangements are made for a red light to glow when a signal drop of 60 per cent is recorded. To detect smaller area films than can be found by the low frequency method, the frequency is increased. The ultrasonic beam then becomes narrower, and only one receiving crystal is used with one transmitting crystal, and the time taken to examine a tyre becomes greater. For detecting internal films smaller than $\frac{3}{8}$in. by $\frac{3}{8}$in. the same method has been used but at 180kc/s using quartz crystals $\frac{1}{2}$in. in dia. The ultrasonic beam emitted from these crystals is nearly plane, and it is necessary to use a separate transmitter for each receiving crystal. With a plane beam, using a transmission method, the area of crystal largely governs the minimum film area which can be detected. To scan a large area of tyre in one revolution six transmitting crystals are used with six receivers. The transmitters are all driven from one oscillator.

The electronic equipment is of standard design, and has been manufactured by the General Electric Co., Ltd. For a standard tyre tester one oscillator and six receiver amplifiers are used. The oscillator consists of a Z77 pentode connected as a shunt-fed Colpitt's oscillator driving an N78 as the output valve. The receiver amplifiers consist of two Z77's, the first being tuned, the second untuned. The output of the second valve is split and fed on to a double diode. One part of the rectified signal passes through a D.C. meter for visible indication of the signal strength and the other rectified signal is D.C. amplified using another Z77 with a relay as the anode load. The operating point of the relay, which switches a lamp, is adjustable so that the light can be made to indicate different signal drops. These amplifiers are used both at 50 and 180kc/s by using plug-in type coils. These are all driven from the same power pack and each unit slides into a rack and is connected to the various supplies by a miniature Jones plug. A spare transmitter and a receiver amplifier are supplied. It has been found that the electrical equipment gives very satisfactory service and requires the minimum of servicing.

The transmitting and receiving crystals are identical and must be mounted in watertight crystal holders. A typical holder is shown in Fig. 2 and the crystal is stuck on a rubber plug with an adhesive which gives an extremely good bond strength. The plug and crystal are then pushed into the brass holder and a co-axial lead is taken from the back of the crystal to the amplifier or oscillator. Rubber or P.V.C. tube is then placed over a collar at the

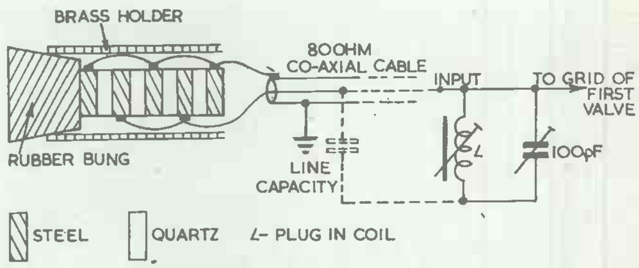

Fig. 2. Crystal and matching network

back of the crystal holder, to prevent water getting into the crystal. At least 10 feet of 80-ohm co-axial cable is used to take the leads from the crystals to the electronic equipment.

No attempt is made to match the crystal impedance to the cable impedance, but the loss of signal in the leads caused by capacitance is largely eliminated by placing an inductance and a variable capacitor in parallel with the line capacitance, as shown in Fig. 2.

The standing wave phenomena, which occurs especially when small tanks are used, can largely be eliminated by using a white noise generator. The white noise generator consists of a germanium diode, which produces electrical noise, followed by a tuned amplifier circuit. The generator transmits oscillations about 45-55kc/s. A thyratron has also been used to produce random noise in place of the germanium diode with very good results. The transmitting crystal emits a random range of frequencies about the fundamental crystal frequency. These noise generators, also manufactured by the G.E.C., are very useful when working in small tanks because standing waves are much more troublesome than when working in a large water tank 6ft by 2ft by 2ft 6in.

Other applications of the method have shown that similar fault areas can be found in other materials besides rubber, particularly thin heterogeneous materials. An interesting example is the detection of air blisters in "green" tiles in the ceramic industry. In this application it is not possible to wet the tile, but it has been found that by using soft rubber pads on the transmitting and receiving crystals, the basic methods will work without water contact, although they lose some of their sensitivity. The soft rubber pads are pressed lightly on either side of the tile.

Rubber Thickness Measurement

Another ultrasonic application has been the determination of rubber thickness when only one surface is available, in the range 3-20mm to ± 1mm. Again, because of the high absorption of the ultrasonic waves in rubber, it was not found possible to use the commercial pulse ultrasonic equipment. A phase lag method has been developed which compares the phase of a transmitted and received ultrasonic wave at 50kc/s. Two identical 50kc/s crystals are placed side by side on the rubber surface. Ultrasonic waves are transmitted into the rubber and reflected from the inaccessible rubber/air boundary. The reflected wave is then detected by the receiving crystal. The received wave lags in phase behind the transmitted wave and the difference of phase will depend on the thickness of rubber. This phase difference is determined by applying the transmitted wave to the X plates of a cathode-ray tube and the amplified received wave to the Y plates. A simple Lissajous figure is formed and the shape of this figure determines the rubber thickness. A phase change of 360° corresponds to a rubber thickness variation of 15mm at 50kc/s. Typical figures taken from the cathode-ray tube are shown in Fig. 3. In addition to this phase lag, an amplitude change occurs with the variation of rubber thickness. This amplitude change can be utilized to resolve

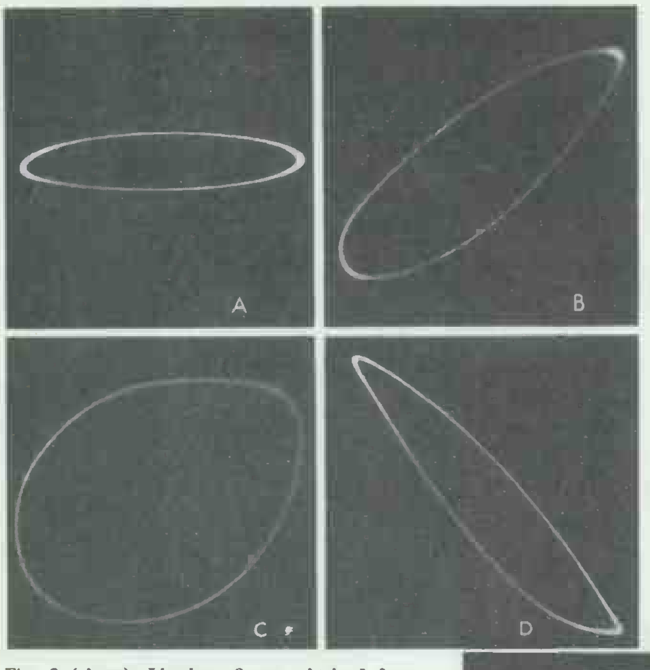

Fig. 3 (above). Lissajous figures obtained from rubber thickness measurements. (A) 8mm. (B) 11mm. (C) 14mm. (D) 17mm.

Fig. 4 (right). Ultrasonic thickness gauge

some of the phase ambiguities. The apparatus uses the same type of transmitter and amplifier as the equipment for detecting internal films in solids. Fig. 4 shows the complete equipment and crystal assembly.

It is found in practice that a certain amount of training and technical knowledge is required to work these ultrasonic instruments efficiently.

High-Powered Ultrasonics

High-powered ultrasonic waves may have industrial uses but various factors prevent their application on a large scale. Using a high-power ultrasonic generator, a number of problems have been examined. These are (a) de-gassing of liquids, (b) dispersion of solid particles, (c) copper and brass plating of aluminium, (d) internal heating of solids. The type of laboratory equipment used is shown in Fig. 5; here the waves are shown being focused by a watch glass, causing an oil fountain. Two DET. 12 valves in push-pull have their anode load matched into 80 ohm co-axial cable which feeds into a transformer placed in a box underneath the transmitting quartz crystal. The transformer matches the 80 ohms input to the high crystal impedance. The crystal is immersed in a bath of oil and approximately 100 watts of ultrasonic energy is available at 300, 650, and 1000kc/s.

De-gassing of Liquids

Of the problems investigated the most promising is the de-gassing of liquids.

The method of de-gassing liquids continuously on a small scale is shown in Fig. 6 and is very effective in removing minute visible air bubbles from viscous liquids such as latex, provided the viscosity is not too great. The present method of de-gassing and by far the cheapest is to use a vacuum method, but the ultrasonic method is very quick and may find applications for this reason. The air bubbles are removed by the reflexion of the ultrasonic waves from the air layers and the pressure of these waves is such as to push the minute bubbles to the surface. For very viscous liquids it is found, with the present power available (100 watts) that the absorption in the liquid is too high and there is insufficient pressure to push the air bubbles to the surface. The de-gassing of large quantities of liquids would present a major problem, but there is no reason, apart from expense, why a large number of crystals should not be used in parallel with a high power electrical oscillator.

When it is essential to obtain maximum ultrasonic power in the liquid to be treated, containers with ultrasonically transparent windows must be used. Thin P.V.C., rubber, or polythene sheeting is suitable for this purpose. Another improvement would be the use of barium titanate crystals when they become generally available Because of their low impedance they could be put directly into the latex or liquids of low resistance, and the oil bath could be dispensed with.

Dispersion of Solid Particles

A second problem which has been investigated is the dispersion of solid particles, particularly carbon black, in liquids by ultrasonic treatment. The general results of this work are that dispersions of carbon black of low dilution and of very fine particle size can be formed; and also that coagulation of the black particles can be made to occur, depending upon the concentration of the solid, frequency, amount of ultrasonic power, and time of treatment. Recently, in conjunction with the British Paper and Board Industry Research Association, it was found possible to re-disperse Dow polystyrene latex 580 G. by ultrasonic treatment. This solution is used for calibrating electron micrographs and is unique in having uniform particle size. Here the normal methods of dispersing the solid had failed.

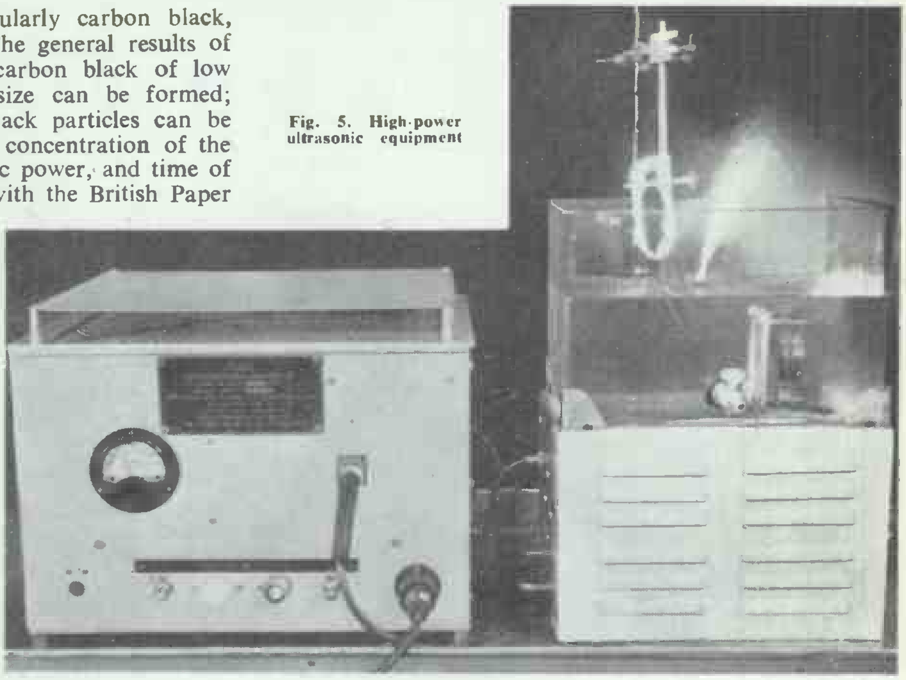

Fig. 5. High-power ultrasonic equipment

Copper and Brass Plating of Aluminium

A further problem investigated was the plating of aluminium with brass or copper and Fig. 7 shows the experimental arrangement. The plating of aluminium by normal electrolysis is not practicable because the copper or brass fails to adhere to the metal. It was found that by irradiating the aluminium cathode during electrolysis with ultrasonic energy, brass plating could be carried out and a layer of brass could be made to adhere to the aluminium. However, the power and time of ultrasonic treatment are critical. Investigation of this problem was discontinued because chemical methods have been developed which do not require brass plating of the metal to give good bond strengths of rubber to metal. This problem is similar to the soldering of aluminium and an ultrasonic soldering iron is now commercially available.

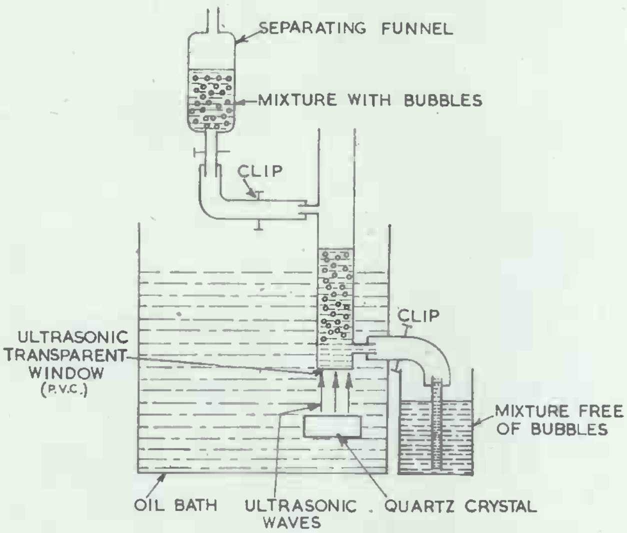

Fig. 6. Apparatus for de-gassing of liquids

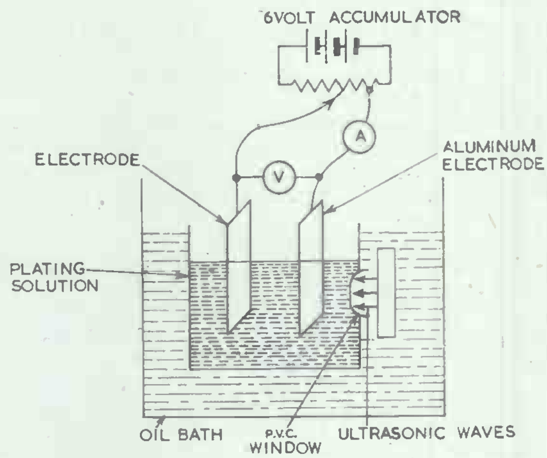

Fig. 7. Plating of aluminium

Internal Heating of Solids

It is not generally realized that high-power ultrasonic waves can be used to heat up many solids internally. It is interesting that polythene, which is not amenable to H.F. heating, can easily be heated by high-power ultrasonic waves because of the high absorption of the waves in polythene.

It is likely that high-power ultrasonic waves will only be used in industry when the problem cannot be solved in any other way, but it is interesting to note that recent trends in the design of practical high-power ultrasonic generators in Germany[1] have been to use magnetostriction or piezoelectric transducers connected as a quenched spark transmitter. The initial cost of the spark transmitter is much cheaper, and the depreciation per working hour is a quarter of that of a normal valve generator.

Acknowledgments

The authors wish to thank the Technical Director, Dunlop Rubber Company, for permission to publish this paper. Thanks are also expressed to members of the General Electric Company for their assistance in the development of this work.

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Electronics in Resistance Welding

By P. Huggins*, A.M.Brit.I.R.E.

THE art of resistance welding springs primarily from the blacksmith's forge. The smith's technique is to heat two pieces of metal in a forge for long enough to bring the metal to a plastic state: then to hammer them until they fuse together and form a welded union. The parameters (i) rate of application of heat, (ii) the time for which the heat is applied, and (iii) the duration and force of the hammering, decide the quality of the weld.

The resistance welding process sets out to duplicate this principle, in a fast, controllable, and semi-automatic manner. The heat is produced by passing a comparatively high current through the metal junction to be welded (the "work"). The duration of the current flow is timed (usually electronically) and is very short (0·01-3secs.) compared with the blacksmith's weld. This short time, which is possible because of the extremely local application of the heat accounts for the speed and economy of the resistance welding process. The smith's hammer is replaced by a pressure system.

Spot Welding

The most generally known form of resistance welding is probably spot welding, and for the purpose of this article all welding control is considered with reference to spot welding. In spot welding, two or more sheets of metal to be joined are placed between copper electrodes. These electrodes are supported on the upper and lower arms of the machine. The upper arm is controlled by an air, or hydraulically operated cylinder which lowers the electrode tip on to the work and applies pressure during the weld (Fig. 1).

These arms are in turn connected to the specially designed transformer secondary. This secondary consists of flexible copper bands or flat braided cable for small machines, or heavy water-cooled copper sections for large machines. Interleaved between the secondary sections are a number of primary coils or "pancakes" built up of copper strip insulated between turns. The ratio of the transformer varies but is in the order of 100:1. The secondary sections are connected to the upper and lower arms, so that the whole configuration forms virtually a single turn secondary. It is thus that the necessary impedance matching between the mains and the low resistance "work" is effected.

The cross-sectional area of this highly conductive secondary loop narrows down at the electrodes to the tip diameter: this is a small fraction of the mean cross-sectional area of the secondary loop. It will be appreciated that when these tips are brought to bear on the metallic work, the total resistance at this junction is greatly in excess of that at any other part of the secondary loop. Hence, although the secondary current is actually limited by impedance considerations, the rate of heating in the secondary is $I_s^2 R_t$ (where I_s is secondary current and R_t total secondary resistance including work). And as R_t consists principally of resistance associated with the work, it is at this junction that the main heat is developed and the weld takes place.

A.C. Welders

Most welding plant falls into this category. The primary of the welding transformer is connected to a single phase mains supply and a contactor makes and breaks one, or both, input lines. The welding is, therefore, performed at 50c/s.

Basically the sequence of operation is as follows:—

(1) The welding electrodes are brought down on the work and pressure is applied.

(2) A contactor in the primary of the welding transformer is closed allowing welding current to flow for a timed period.

(3) The contactor opens at the completion of the weld, but the pressure on the weld is maintained.

(4) Pressure is removed and electrodes are separated.

The weld is now completed.

The main contactor itself can be either electro-magnetic or electronic, the choice being a question of cost and welding application. The high speed of operation (as short as 3/50th sec) and the consistent operating performance, make the design of the magnetic contactor a specialized affair, especially if it is to be synchronous (opening at zero current) and carry high currents.

The electronic contactor invariably has two ignitrons connected in inverse parallel in series with the primary of

Fig. 1. Standard type of spot and stitch welder

* *Sciaky Electric Welding Machines, Ltd.*

the welding transformer (see Fig. 2). One tube rectifies the positive half cycles and the other the negative, thus making the circuit virtually a contactor. The application of the igniting potential which is necessary to make the tubes conduct can be via a small contactor or from triggering thyratrons. The latter method is preferable where superior welding control performance is required; since by controlling the firing point of the thyratron, the duty cycle of the ignitrons (and consequently the weld heat) can be manually or electrically varied[1].

In exceptional circumstances, one ignitron only is used—$\frac{1}{2}$ cycle welding[2]—and if the welding current is very small as in welding electrode assemblies in valves, thyratrons are used in lieu of ignitrons. At the other end of the scale, if the largest ignitrons manufactured cannot cope with the demand kVA, it is possible to double-bank them, and commutate rapidly from ignitron to ignitron throughout the duty cycles[3]. It is not possible to operate ignitrons in parallel, as they are mercury arc devices, but in some welder transformer designs it pays to have two parallel fed transformers feeding into the welding work.

Special Features on A.C. Welders

The design of standard A.C. welders is not always quite so simple as that outlined above. The requirements may call for any, or combinations of the following:—

Multiple Pressure Cycles

Instead of having a constant pressure applied throughout the weld, a variable pressure curve may be required. A typical example is: a high pressure before weld to make good contact, a low pressure during weld to increase heat, a high pressure after weld for forging. The timing and sequencing of these pressure cycles is usually a simple problem.

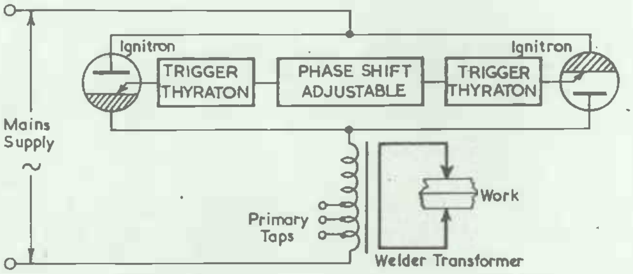

Fig. 2. Single phase ignitron contactor with heat control

Preheat

A lower level of heat is required for a predetermined time before the main welding heat is applied. This can take two forms (i) two distinct heat levels (ii) a gradually rising heat, starting from zero and culminating with the weld heat, known as "slope control"[4]. Machines fitted with "slope control" are able not only to preselect the duration of the preheat, but its rate of rise as well. Preheat systems invariably work in conjunction with ignitron contactors having thyratron control.

Postheat

The complement of preheat. Here again the welding requirements may have to be met with a definite postheat current level, or alternatively, with a continuously changing current level teminating at zero current.

Automatic Compensation

If the mains voltage fluctuates, the heat in the weld will follow these fluctuations roughly "square law" and, unless counteracted, this may impair welding quality. While a good welding engineer will be aware of the change in the weld quality by visual inspection; this is not the case in mass production line machines operated by semi-skilled labour.

Again in the case of machines used for welding mild steel sheet or drums, etc., the presence of the magnetic material in the leakage field affects the impedance and, therefore, the welding current[13]. If, as the welding progresses, the sheet or drum travels into the "throat" of the welder arms, the inductive reactance of the load is increased and the welding current diminishes.

Automatic heat compensation for mains voltage fluctuations is obtained in a number of ways. One method is to fit taps on the transformer primary with an auto-selective contactor arrangement. A more popular and less costly method is to have a weld timer whose timing accuracy is a function of the mains voltage. If the mains voltage falls, say, by 10 per cent, the weld time automatically extends, say 20 per cent to keep the total energy imparted to the weld approximately constant. This method is, however, only effective for certain classes of welding where the plastic range of the metal is fairly wide. A superior method, embodying the heat control principle, can be incorporated on equipment employing trigger thyratrons to ignite the ignitron contactor. There are then two controls: the manual heat control and the automatic heat control compensator whose setting is determined by a feedback system using a standard voltage reference and an "error signal". The actual circuit arrangements involved depends largely on the designer[5], but the time-constant of the system is sometimes important. For instance, a device incorporating a magnetic amplifier having a time-constant of three or four cycles at the mains frequency may provide adequate compensation for slow drift in mains potential. It will not, however, compensate for short duration mains variations caused by neighbouring welding plant, and other intermittent loads, and occasional bad welds will result.

Another approach to the problem is to monitor the welding current, and use a feedback system to correct the current as it tends to change. This method, which uses a reactor in series with the welder primary, compensates for any factor effecting a secondary current variation, i.e., voltage fluctuations, changes in secondary impedance due to presence of work, dirty or scaly material, etc., and affords the most complete compensation possible to date.

There are also one or two timers in which the weld time is automatically governed by the total energy expended. One of these operates on the "watt-hour meter" eddy current principle. Another has a specially designed feedback transformer whose output potential when driving the timer is a non-linear function of the welding current. In both timers changes in secondary impedance, dirty material, etc., are catered for as well as mains variations. In many cases, this is a satisfactory solution; but from a welding point of view, maintaining the energy imparted to the weld by changing the time parameter is not always as effective as the current compensation methods.

Automatic Feed

Many welding machines incorporate mechanical, or electro-mechanical, systems for feeding the component parts into the welder, for setting up the components prior to welding and for subsequently ejecting them after welding. In some cases the automatic feed incorporates such processes as cropping, bending, pressing, etc., the welder being a homogeneous plant.

The design of such plant is, of course, to individual specification and adds to the cost of the machine. Where long term production of a special article is envisaged, the eventual saving on handling time offsets this cost.

As yet electronics has not made any great inroads into this aspect of welding machines—the circuits being mainly of an electrical nature. Photocell techniques are sometimes used.

The Stored Energy Welders

The conventional A.C. welders suffer from the disadvantage that the demand on the mains is spasmodic, single phase, and usually of low power factor. Except for the more recent 3-phase balanced load frequency convertor system to be described, the problem of "spreading the load" and reducing its transitory nature, has been tackled by energy storage systems. For example, motor generator sets having large flywheels have been used to supply the welding energy. The inherent cost, and the poor regulation, of this method has led to the commercializing of the so-called "D.C. Welders." There are three versions of these:

1. Battery type.
2. Inductance type.
3. Capacitor type.

Only types (2) and (3) are manufactured in this country, and the basic system in each case is broadly as in Fig. 3. The three phase supply is fed into a conventional polyphase rectifier system whose design depends largely on the manufacturer. Ignitrons, mercury arc rectifiers and metal rectifiers are variously employed in this connexion. The rectifier "load" is the D.C. storage device: be it battery, inductance or capacitance. The storage element is in turn discharged into the weld via the usual current step-up ratio transformer. By careful design it is possible to make the inductance of the welding transformer itself serve as the storage device with method (2). Method (1) uses lead acid cells and (3) uses electrolytic capacitors.

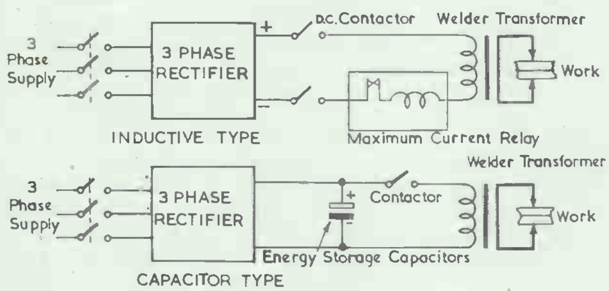

Fig. 3. Energy storage systems

The success of the system in each case depends upon the fact that the charge time of the storage component is much greater than the discharge (welding) time. Energy storage welding is characterized by the heavy application of current for relatively short time without the usual high kVA demand on the supply service, and it finds its greatest application in the spot welding of light alloys[6].

Physical factors limit the amount of storage energy. Consequently, the question of saturation of the welding transformer by the D.C. discharge through it, does not usually arise.

Frequency Conversion Welding

Mains frequency welding suffers from certain disadvantages brought about by reactance effects at 50c/s. Most important of these are: dimensional limitations of the secondary loop area (i.e. the configuration of the welder arms), and the changes in welding current brought about as the material being welded is introduced into the throat of the machine. Another point to be borne in mind is that the heat curve will have a frequency of 100c/s and that in practical applications the heat produced tends to dissipate into the surrounding media during the current nulls.

Reducing the welding frequency, therefore, has its attractions. Motor generator sets of the type mentioned earlier, designed in France had an output frequency of $16\frac{2}{3}$c/s. By employing grid controlled rectifier techniques, ingenious electronic frequency conversion system are possible—a number of which have been patented. Two methods are described below; one based on a single phase supply and one on a 3-phase system.

Single Phase

A recent patent[7] describes an electronic control and welding system, which can be condensed to the basic circuit shown in Fig. 4. The A.C. mains is applied via a centre tapped welding transformer primary to two ignitrons. These ignitrons are sequentially fired so that IGN No. 1 conducts for a pre-selected number of half cycles of the mains supply, then both ignitrons are made non-conductive, followed by IGN No. 2 conducting for a similar number of half cycles and so on until the weld is completed. The conventional direction of current flow will be as in Fig. 4. The actual number of half cycles conducted by the ignitrons before reversing the current determines the welding frequency, and the lowest frequency available is only limited by the transformer design. The duration of the weld time, the welder frequency, the firing angle (duty cycle) of the tubes, and the synchronization into the mains supply are electronically controlled.

Three Phase

The "Sciaky" patent balanced load system[8] is an example of the three-phase frequency-changer system. It employs six ignitrons in inverse parallel pairs connected in delta to a specially designed welding transformer. The ignitrons

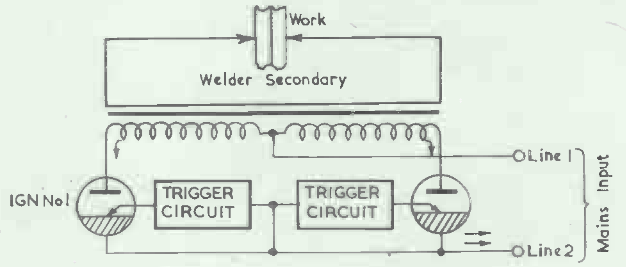

Fig. 4. Single phase frequency-conversion

are controlled in two groups of three tubes each (1, 2, 3 and 4, 5, 6 in Fig. 5). Every tube in a group is connected in a direction corresponding to one polarity of induced E.M.F. The tubes of the other group are connected to correspond to the opposite polarity of secondary E.M.F.

At the commencement of the weld, the control circuit first blocks one group of ignitrons. The tubes of the other group are permitted to operate, and each carries current when its anode/cathode potential is in the proper direction. Consequently the tubes of this group take turns carrying the current. Current commutates from tube to tube, so that current is transferred to the primary winding having the highest applied voltage of the proper polarity. The current in each winding induces a voltage in the secondary of the same polarity. This current builds up in the secondary and is maintained in the same direction for several supply frequency cycles. Then *all* tubes are blocked off and the current allowed to fall to zero. Next the other group is permitted to operate and current built up in the secondary in the opposite direction and so on, until the weld is "timed out" as completed. The unique feature of this system is that although single phase current alterations in the secondary are in the region of 5c/s, the load is evenly distributed across the 3-phase supply.

There are numerous electronic problems associated with the design of such equipment—especially as it has been found that by "tailoring" (shaping) the low frequency welding waveform, particularly high quality welding can result[8-10]. Another problem recently solved was the elemination of the "gap" between each impulse of secondary current—thus reducing the heat dissipation loss when the current falls to zero.

Conclusion

Electronic systems are improving weld control in all types of welding machines. Although only spot welders have been mentioned, corresponding advances have been made in other lines such as seam, stitch, flash-butt welding, etc.

There has been a tendency for the electronic design to outstrip the welding research, with the result that the capabilities of some systems are not as yet fully explored. Whereas in some simple applications, electronic controls are an unnecessary refinement, the fact that electronics has come to stay in this industry is borne out by the manufacturer's acceptance of the inevitable servicing problem, and the efforts that are being made to combat it[11].

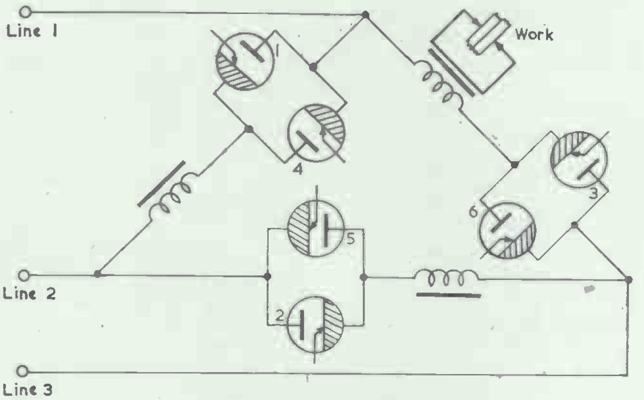

Fig. 5. The Sciaky three phase circuit

Future Trends

At the moment, the tendency is for control equipment to get more and more complex; valves are replacing relays: dekatrons are replacing uni-selectors. Successive designs will, however, undoubtedly swing towards more elegant electronic techniques, with consequent reduction in component parts.

The use of electronic test apparatus to analyse or monitor the welding parameters is on the increase. Strain gauge techniques for pressure analysis, dekatrons for time measurement (in cycles)[12], and integrating amplifiers for low frequency welding current measurement, are but some of the many auxiliary electronic applications to the actual welding machine.

Electronic motor control has recently been introduced very effectively for certain applications such as indexing seam welders and will find further uses.

Electronic sorting, counting and batching techniques may also find applications in fast high speed automatic indexing type welders.

Over a number of years, considerable collective effort has been put into the problem of originating systems of resistance welding, and no great innovations would, therefore, appear to be forthcoming in the immediate future. There might, however, be scope for dual applications of both resistance welding and induction heating; also for resistance welding and ultrasonic techniques.

Welder Ratings

A final note in this connexion, because the writer finds most personnel in contact with welders misunderstand the kVA ratings of the machines. The kVA rating of resistance welders means "The welder, if loaded to the kVA rating on the nameplate, will carry that kVA at a 50 per cent duty cycle and not exceed the temperature rise indicated on the nameplate"[13]. Thus the kVA rating is a *thermal* one, and in no way specifies the welding capacity. The latter is a function of pressure, secondary current (and its waveshape), and the duration of flow. This explains the apparently anomaly that two 75kVA machines may seem to have different welding capacities.

Acknowledgments

The author wishes to thank the Directors of Sciaky Electric Welding Machines Ltd. for permission to publish this paper.

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ELECTRONIC INSPECTION OF WIRE ROPES

Wire ropes in service in mines and elsewhere are dependent on daily visual inspections, periodic detailed inspections and test samples from the socket end for their safe operation.

The daily visual inspection, especially if the rope is covered with lubricant or dressing, may detect only gross faults. The periodic detailed inspection, which is applied to suspected weak points and certain points at specified intervals, can give a fair indication of external rope conditions at these points. Every inch of rope should be inspected but with a rope of a mile or more in length, proper inspection becomes a serious problem. The testing of a sample from the socket end of the rope at monthly or quarterly periods gives the engineer a check on his visual and detailed inspection at the socket end. The remainder of the rope is judged by a comparison of the inspection results. The need of a method of inspection and testing that will cover the entire rope while it is in service without interrupting the normal hoisting cycle has long been felt.

An electronic method for the inspection of wire ropes while in service was described by W. Simpson, Mechanical Inspector for the Nova Scotia Department of Mines, at the Seventh International Conference of Directors of Safety in Mines Research at Buxton earlier this year.

The new apparatus inspects every inch of the rope regardless of its visual state. Gross faults not found by colliery inspectors are easily detected. Other deteriorative conditions such as changes in rope diameter, increasing hardness, plastic flow, minutely crushed spots at cross-over points, state of fatigue and corrosion are identified by carefully evaluating the effects of each on Cyclograph results.

A specially designed mobile testing truck, insulated and equipped with improved shock absorbers, houses the equipment, except the Running Dynamometer, which is installed on the rope with test coil. The principal equipment is the specially designed Cyclograph for rope testing; the Running Dynamometer complete with Selsyn transmitting units, calibrated springs, etc., for measuring the load on the rope when in motion; two Esterline-Angus recording meters complete with Selsyn drive; time marker and controls (one meter to record Cyclograph readings and the other to record Dynamometer readings); one intercommunicating unit, which permits communication between the truck and the hoisting engineer and one 100W, 110V, 60c/s voltage regulator.

The Applications of Electronics in the Textile Industry

By A. A. Atkins*, B.Sc. (Eng.), A.M.I.E.E., A.M.I.Mech.E.

THE principal applications of electronics in the textile industry at the present time are largely in the field of measurements. This is particularly so in the yarn manufacturing and processing divisions as it is not economically possible to apply elaborate control apparatus to each individual end of yarn when there may be many thousand ends on a single mill floor. When the yarn is knitted or woven however, then the cloth is frequently treated on automatically controlled machines.

During manufacture and processing, the yarn may be rotating or reciprocating at high speed and it is subject to small forces which are usually fluctuating at frequencies which may be up to a hundred or so per second. The yarn is therefore frequently difficult to see and it is not easy to measure or record its tension accurately. Electronic apparatus can help both problems.

The Stroboscope

The stroboscope was probably the first electronic device to be extensively used in the textile industry and it is too well known to need describing. It is extremely convenient for checking bobbin speeds, and is a valuable aid in observing the yarn during spinning and twisting.

There are however three modifications to normal stroboscopes which are of interest.

It is usually considered that the minimum flashing rate for satisfactory persistence of vision and absence of flicker is about 600 flashes per minute. This is too fast for observation of the motion of the shuttle in a loom which may do 50-100 complete cycles per minute (100-200 "picks" per minute). If, however, the flash intensity is increased sufficiently, the flash timed by a contactor driven by the loom, and preferably, the general illumination reduced, satisfactory observation of the shuttle and yarn is then possible. It is usual for the angular setting of the contactor to be manually variable by remote control so that the phase of the flash can be conveniently adjusted. A complete stroboscope made specially for this purpose is the "Stroboloom" which is illustrated in Fig. 1.

When twisting and winding yarn on to a bobbin by the ring spinning process, the yarn balloons around the rotating bobbin and drags a small "C" shaped metal traveller around a precision ground ring.

As the yarn is usually built up on the bobbin with a profile that is not cylindrical (a conical shape is frequently used), the yarn does not balloon around the bobbin at constant angular velocity although the bobbin is being rotated at constant speed.

A stroboscope can be synchronized with the yarn and traveller if an electro-magnetic pick-up is placed just outside the ring. As the traveller passes the pick-up, it generates a pulse which after amplification, is used to trigger the stroboscope[1].

Induction Motor Slip Measurement

In viscose and acetate rayon manufacture, the yarn is collected in a "Topham" box or on a bobbin which is driven by a high-frequency squirrel-cage induction motor at 5 000-10 000 R.P.M. The condition of the bearings in these motors can best be assessed by checking the slip of the motor which is about 4-6 per cent on normal load.

If the stroboscope were used in the usual manner, it would need to be very accurately calibrated and it would also be necessary to determine precisely the frequency of the supply to the motor. This supply, if provided by an induction type frequency changer, may vary with load, with the frequency of the 50c/s mains or with belt slip.

An electro-mechanical frequency divider has been developed which triggers the stroboscope lamp to flash at a speed equivalent to exactly 4 per cent or 8 per cent slip quite independently of variations in the frequency of the spindle motor voltage. It consists of a phonic motor, which rotates synchronously with one revolution for each one hundred cycles of the spindle motor supply.

The spindle of the phonic motor carries two accurately divided gears with 48 and 46 teeth respectively. An electro-magnetic pick-up is placed close to each gear and pulses are generated at tooth frequency. The appropriate pick-up or a small fraction of the motor supply voltage is selected by a switch and fed to a single stage amplifier whose output triggers the stroboscope.

A two pole motor with 4 per cent slip will appear stationary if the stroboscope is triggered by the pulses from the 48 tooth gear, one flash occurring every two revolutions of the motor.

Slips up to about 10 per cent, other than exactly 4 per cent or 8 per cent are estimated from the apparent speed, either forward or backward, when the motor is observed with the stroboscope triggered synchronously or at either of the two slip speeds.

Fig. 1. The Dawe "Stroboloom"

* Courtaulds, Ltd.

Yarn Tension Measurement

The most common instrument for measuring yarn tension is the pocket-size dial tensiometer consisting of a case with one or two fixed arms and a moving arm all carrying small ball-bearing V-pulleys. The yarn passes around the pulleys and the tension is balanced by a spring connected to the moving arm which also actuates a pointer. In some cases the movement is damped.

This type of instrument gives a useful indication of the mean tension but the reading of the undamped tensiometer may be difficult if the tension is fluctuating appreciably at a frequency near the low natural frequency of the tensiometer movement. The minimum full scale deflexion is usually about 25 grams and this is not sufficiently sensitive when measuring tension of the order of one or two grams.

As there are nearly always appreciable tension fluctuations in moving yarn, it is considered that it is necessary to record the yarn tension measurement before the fluctuations can be studied.

Yarn tension cameras have been made which accurately follow tension fluctuations up to more than 100 cycles per

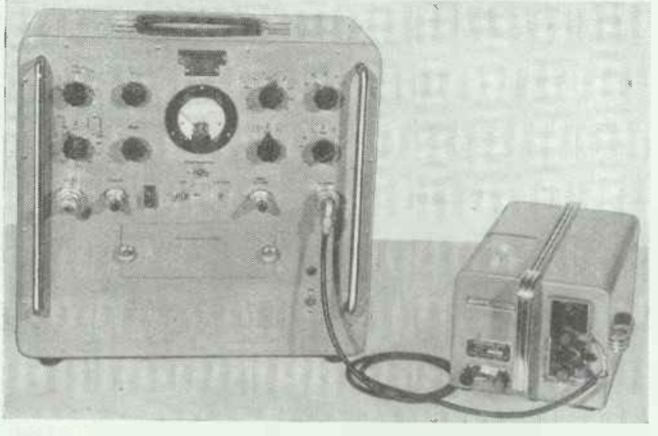


Fig. 2. Single channel strain gauge recorder and amplifier for use with the yarn tension pick-up

second but the subsequent dark room developing is tedious and changing the sensitivity may mean changing a spring and also altering the damping.

Electronic yarn tension recorders are now available which give an instantaneous record and have adjustable sensitivity at the turn of a switch.

The problem of the dynamic design of a pick-up with an adequate high-frequency response is fundamentally one of measuring small movements as there is a practical limit to which the weight of the moving ball-bearing pulley and its mounting can be reduced.

Variable inductance, variable capacitance and both bonded and unbonded resistance strain gauge elements have all been used in yarn tension pick-ups but it is considered that the greater sensitivity which can be obtained with the variable inductance type make it preferable. This type of pick-up was developed by Kelvin and Hughes, Ltd., for use in conjunction with their single channel strain recorder. The pick-up consists of a pistol-shaped handle, which carries two guide pulleys and a third pulley is attached to the armature of the coil unit. All three pulleys are mounted on miniature ball bearings. The armature is suspended by a pair of metal diaphragms which permit axial movement. The trigger moves the coil unit and armature pulley forward so that the latter passes into a hollow in the pistol nose. This arrangement makes the pick-up self threading and as the yarn path is only increased by about ¾ in., it can usually be threaded without stopping the machine.

The coil unit consists of three coils, the two outer coils being connected in series opposition and fed by a 2kc/s oscillator. The yarn tension moves the armature which alters the mutual inductance of the three coils. This causes a voltage to be induced in the middle coil which is connected to the input of an amplifier via a ten position gain control.

The unloaded pick-up is initially adjusted to zero by centralizing the armature. An auxiliary spring and an axial adjusting screw is fitted for this purpose. Additional balance controls are provided on the oscillator/amplifier unit shown in Fig. 2.

After amplification, the modulated 2kc/s signal passes through a phase-sensitive demodulator. Further amplification is provided by a D.C. amplifier which drives the recorder. Its moving coil is supported by a taut strip suspension and the stylus makes a fine black trace on Teledeltos paper, which can be driven at any of six speeds from 0·25 to 10cm/sec. The normal full scale deflexion of the stylus is 2cm each side of a centre zero but for yarn tension recording, the stylus is usually biased to one side and 3·5 to 4cm deflexion is available. Maximum sensitivity is about 1·4cm/gram and maximum permissible load for the pick-up is 150 grams. Values of tension up to this figure can be accommodated by the gain control which reduces the sensitivity by a factor of 2 in each step.

The overall frequency response of the equipment is uniform within 6 per cent up to 60c/s. The pick-up natural frequency is several times greater than this and is substantially damped. The transient response of the equipment can be tested by hanging a weight on a length of yarn threaded through the pickup, and then suddenly removing the load by cutting the yarn. With care a clean cut can be made and the transient recorded on the fastest paper speed. The equipment is also calibrated by hanging weights.

If one is interested in the average value of a particular yarn tension, then a capacitor can be inserted across the input to the D.C. amplifier and the fluctuations smoothed out.

Tension fluctuations of 140c/s have been recorded on the equipment illustrated, but their amplitude was appreciably attenuated by the droop in the recorder response at this frequency. An alternative recorder with a level characteristic up to 90c/s is commercially available, but the deflexion is reduced to ±1·2cm.

A comprehensive description of another electronic yarn tension recorder using an unbonded resistance strain gauge pick-up has been recently published[2].

Yarn Load-Extension Testers

Electronic tension recorders can also be used in conjunction with auxiliary equipment to provide load-extension curves for yarn. Such an arrangement using resistance strain gauge load cells has been described[3]. A high frequency response is not so necessary in this type of equipment and this simplifies the pick-up design.

A recording yarn tensile tester of British design, which has been available for a number of years, uses a pair of thyratron controlled D.C. motors to apply the load and extension. Either constant rate of loading or constant rate of extension can be used. In this instrument, the load is measured mechanically by the deflexion of a spring.

The "Statigun"

If acetate rayon and nylon are warped under conditions of low relative humidity, there is a tendency for static electricity to be generated by the passage of the yarn through guides on the creel and through the reeds before the yarn is wound on to the swift or beam. This static electricity can be very troublesome and the "Statigun" developed by the Baldwin Instrument Co. Ltd. is a useful tool for investigating its magnitude and polarity.

The instrument consists of a pistol-shaped body which houses a sub-miniature electrometer triode, an anode current meter calibrated in voltage gradients, batteries and the switches and zero-setting rheostat.

On pointing the "Statigun" towards charged yarn, a small voltage will be induced on to the grid of the valve by capacitive coupling and will cause the anode current to change.

Evenness or Irregularity Recorders

During the process of spinning natural fibres or man-made staple fibre, it is desirable to check the evenness or constancy of weight per unit length. This can obviously be done by many delicate weighings of short lengths of yarn but this is a very slow procedure.

Electronic devices of two types have been developed which will give a continuous record proportional to the weight per unit length.

The Fielden-Walker Evenness Recorder

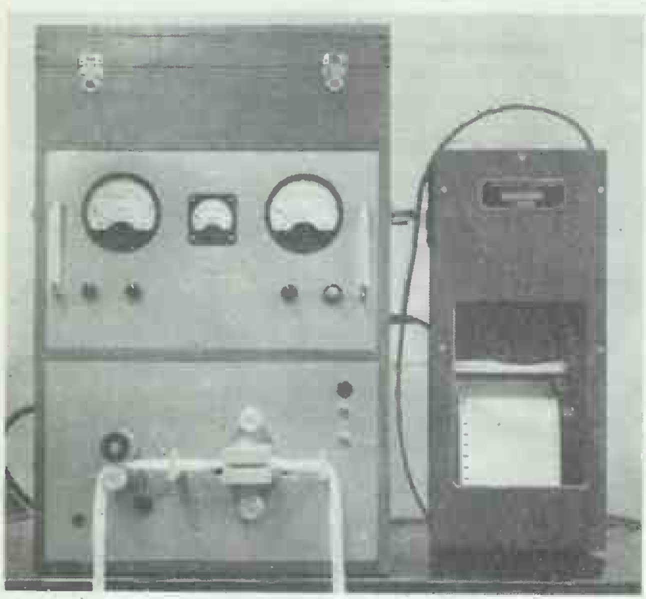
The instrument, illustrated in Fig. 3, measures the change in capacitance of a special capacitor when the yarn is passed between its plates, the yarn acting as a dielectric of variable mass.

In the illustration, the upper section of the left-hand unit houses the radio-frequency oscillator, bridge balance and sensitivity controls, amplifier and indicating meters. The lower section contains the capacitor electrodes with an effective width of one centimetre and a two speed motor for pulling the yarn through the electrodes at speeds of 5 or 50 feet per minute. The recording milliammeter has chart speeds of 1, 3, 6 and 12 inches per minute.

The instrument is fitted with an integrating circuit with a time-constant of about 2 minutes which feeds an indicating meter calibrated inversely proportional to the mean level. A similar meter gives readings of the mean irregularity. The product of the two meter readings is approximately the percentage mean deviation measured over the previous period of about 2 minutes.

Interchangeable capacitor electrodes are provided to suit a wide range of weights of sliver, roving and yarn. In Fig. 3 a sample of sliver is shown passing through the electrodes[4].

Fig. 3. The Fielden-Walker Evenness Recorder



With this method of measurement depending on dielectric mass, the sample being tested must have a uniform moisture content within itself. This is easily achieved in practice by the normal conditioning procedure.

The Dawe "Linra" Irregularity Meter

This instrument is similar to that just described but uses a light beam and photo-cell in the detecting head and it measures the effective diameter of the yarn. The instantaneous results are presented on a recording milliameter and indicating meters are also provided for mean diameter and mean deviation, the integrating period in this case being about ten seconds.

Moisture Measurement

Electronic moisture instruments working on two basic principles are in use in the textile industry. One is the variation of resistance with moisture and the other is the variation of effective dielectric constant.

The Shirley Meter is an instrument of the first type. A direct current is used to measure the resistance of a sample across an electrode assembly consisting of a metal rod surrounded by a metal tube, both conductors being separated by ebonite.

The electrode is applied by pressing it on to the sample by hand until a constant reading is obtained, alternatively a spring loaded constant pressure device can be used. The instrument is intended for use on raw cotton and on grey cotton yarns wound on to any type of package. It is direct reading over the range 4·5 per cent to 15 per cent regain, three overlapping scales being provided on two meters.

Conversion tables are available for use when the moisture meter is used on other raw materials such as woollen and worsted yarns, rayon, linen, etc.

An example of the second class of instrument is the Fielden Drimeter which uses a similar radio frequency bridge circuit[5] to that used in the Fielden-Walker Evenness Recorder previously described. It is particularly suitable for measurements of cloth moisture content. When installed on drying machines the cloth passes between a pair of large electrodes and a continuous indication of the dryness of the moving cloth is shown on a meter. Compensation can be made for variations in the cloth weight of different cloth specifications when commencing the drying of a particular material.

The Drimeter is widely used in conjunction with an Automatic Control Unit to vary the speed of the cloth through the drying machine in order to obtain cloth dried to just the correct moisture content[6].

The use of radio frequency dielectric heating for the setting of twist in rayon and the drying of wool cheeses was mentioned in this journal[7].

An electronic position control servo-mechanism applied to guiding cloth into a drying machine has also been fully described in this journal[8,9].

Acknowledgments

The writer wishes to thank the Directors of Courtaulds, Ltd., for permission to publish this paper.

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Nucleonics and Industrial Applications

By Denis Taylor*, M.Sc., Ph.D., M.I.E.E., F.Inst.P.

JUST as electronics is playing an increasingly important part in the economy of the nation, so in a smaller way, the newer science of nucleonics is gradually leaving the nuclear physics research laboratory and finding applications aimed at producing greater productivity of our industrial processes. The applications are of many types. Thus, an obvious application, which has its counterpart in many industries not concerned with radioactive materials, is the sorting of radioactive cobalt needles. Such needles are used in hospitals for therapeutic treatment and it is necessary that their activity should be properly tested prior to dispatch from the manufacturers. A machine which has been used for the testing and sorting of such needles is shown in Fig. 1. It checks the γ-activity of the needles and sorts them into three bins according as to whether their activities are high, normal or low.

The operation of the mechanism is as follows. An aluminium magazine containing the highly-active cobalt needles is inserted into a lead housing containing a mechanism which automatically selects a needle and drops it into a container. Adjacent to this container is an ionization chamber connected to a counting-rate meter. After a pre-set counting time, relays in the ratemeter output circuits automatically channel a flexible tube to the appropriate collector bin. The container holding the sample under test is then rotated and the needle drops into the bin. At the same time the next needle is prepared for sampling and, when the sample holder completes its rotation, the needle drops into place to be counted and the cycle is repeated.

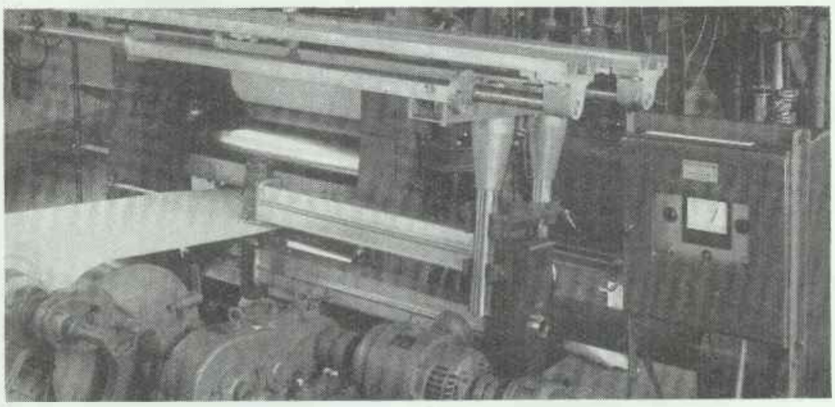
Many other examples can be given of the use of electronic methods which take advantage of the radioactive emissions from the product being handled. A method which has been used in the laboratory and which may find wider application is the method of separating radioactive fission products using an ion-exchange column. In this case the electronic apparatus[1] is used to route the liquid flowing out of the column into a separate bottle for each element. A typical curve of activity against time consists of a series of peaks and troughs, each peak corresponding to a separate element. It is therefore necessary to change to another bottle, either when the activity drops below a predetermined level, or when the activity-versus-time curve reaches a minimum. In the A.E.R.E. apparatus the liquid from the column flows into a flow-through Geiger counter, the counter output being passed to a counting-rate meter of special design. This latter measures not only the counting rate, but also the rate of change of counting rate so that the minima of the curve can be registered. Special precautions are taken automatically in this apparatus to ensure that no more than a certain quantity of liquid passes into any one bottle. This is necessary to avoid overflowing and involves the use of a photocell liquid-meniscus detector.

The ion-exchange column, operating automatically as already explained, has been used at the A.E.R.E. for the separation of the rare earth elements and, in fact, can be applied to deal with nearly all the major fission products.

Nucleonic methods are sometimes employed in a more subtle way, a radioactive material being deliberately introduced into a manufacturing process to produce a desired effect. One such use is in producing ionization in the air in the neighbourhood of machinery on which static charges may be developed. Losses of material and working time, due to the effects of this unwanted static electricity are serious in the textile, paper and plastic industries, and the use of radioactive materials to remove these electrostatic effects appears to have advantages over other methods.

Measurement of Thickness

A further application of the same kind is in connexion with the thickness measurement of paper, plastic sheet and similar materials. In this case a radioactive substance which emits β-particles is used. This is placed on one side of the material to be measured and a suitable detector is placed on the other side. The absorption of β-particles in traversing the material is approximately an exponential function of the absorber thickness, so that the meter circuit associated with this detector-component can be calibrated to indicate this thickness directly. Mathematically, the absorption of β-particles can be represented by the formula



A Beta-ray Thickness Gauge Installation
(Photo by permission of LKB Produkter)

$$N = N_o e^{-\alpha x} \quad \ldots\ldots\ldots\ldots (1)$$

where x is the thickness of the material and α is its linear-absorption coefficient. It is convenient to re-write this equation as

$$N = N_o e^{-0{\cdot}693x/d^{\frac{1}{2}}} \quad \ldots\ldots\ldots\ldots (2)$$

where $d^{\frac{1}{2}}$ is the half-value thickness of the material, that is the thickness required to reduce the intensity by one-half.

It follows from Equation (2) that

$$dN = -0{\cdot}693\, N_o/d^{\frac{1}{2}} \,.\, e^{-0{\cdot}693x/d^{\frac{1}{2}}} dx \quad \ldots\ldots (3)$$

and so the proportional change in N, that is dN/N for a given change of thickness dx is given by

$$dN/N = -\frac{0{\cdot}693}{d^{\frac{1}{2}}} dx \quad \ldots\ldots\ldots\ldots (4)$$

* *Atomic Energy Research Establishment, Harwell.*

which means that the proportional change in N (the measured quantity) is inversely proportional to the half-value thickness $d^{\frac{1}{2}}$.

In practice, therefore, high sensitivity means a low value of $d^{\frac{1}{2}}$, which in turn means choosing a β-emitter with an appropriately low β-ray energy. It might be thought that by choosing a radioactive material, which emits very low energy β-particles, that the half-value thickness $d^{\frac{1}{2}}$ for the material to be measured can be reduced and the accuracy of measurement increased indefinitely. In practice, due to departures from exponential absorption, the optimum sensitivity is obtained in this case when the thickness to be measured is about four times $d^{\frac{1}{2}}$. However, by collimating the radiation on both sides of the material to be measured by a criss-cross of vertical sheets, scattering as well as absorption can be made to contribute to the reduction of intensity produced by the introduction of the sheet material. The optimum sensitivity can then be four or five times as great and this new system is therefore of special value for the measurement of very thin sheets of material (i.e. very low mass per unit area).

In the simplest case, a β-ray thickness gauge comprises a small ionization chamber and electrometer valve or D.C. amplifier circuit with the ionization-chamber detector on one side of the sheet of material to be measured, and with a radioactive source on the other. The passage of the β-particles into the chamber causes ionization of the chamber gas and a small current is collected. This current

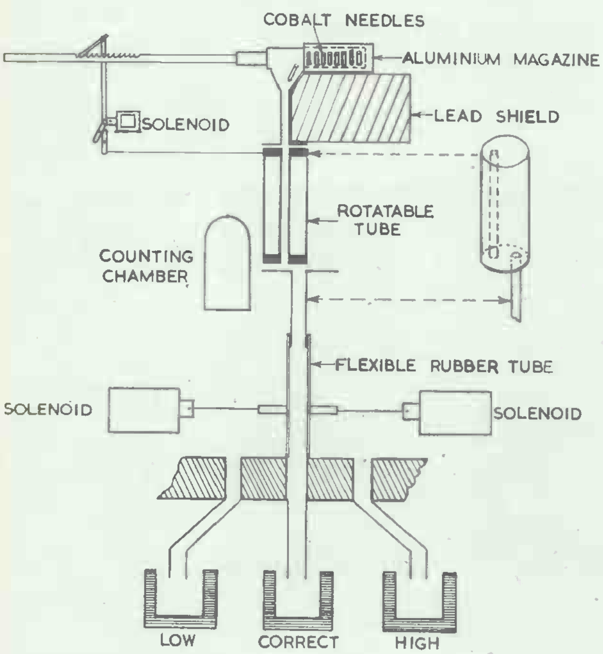


Fig. 1. Outline diagram of cobalt needle sorter

passes through a high-value resistor and the voltage drop across this is applied to the electrometer valve and measured by a backed-off voltmeter in its anode circuit. The meter can be arranged to read zero with a certain standard thickness of material, and departures from this thickness, positive or negative can then be indicated on a centre-zero scale. Alternatively, the meter can be arranged to indicate thickness directly on a calibrated scale. It should be noted that the gauge actually measures the mass per unit area of the sheet material and that this is only proportional to the thickness of the material if it is of uniform density.

One of the main technical problems associated with the design of a satisfactory β-ray thickness gauge is the actual zero stability of the D.C. amplifying system and the different British manufacturers of these gauges (Baldwin Instrument Co., Ltd., E. K. Cole, Ltd., and Isotope Developments, Ltd.), have adopted different solutions resulting in a diversity of thickness gauges with varying merits. In one type of gauge a clock mechanism masks the source used for measurement for a small part of each cycle and presents a standardizing radioactive source to the ionization chamber during this time. Whilst this standardizing source is operating the system, a self-balancing potentiometer is used to re-set the zero of the D.C. amplifier in case it has drifted during the cycle time. In a second type of gauge shown schematically in Fig. 2, the problem is solved by connecting two exactly similar ionization chambers in opposition. The sheet to be gauged is placed between one source and the chamber and a standard sheet of material is placed between the other side of the source and the second chamber. In this way if the standard is the same weight (i.e., the same thickness) as the material being gauged, there is no input current to the amplifier, and the input is either positive or negative according to whether there is any departure, positive or negative from the standard weight. This particular system has become quite popular and is used by many manufacturers. A typical installation of this type due to L.K.B.-Produkter Fabriksaktiebolag of Stockholm, is shown on the opposite page. Still a third method is to use an amplifier of a better type with good zero-stability. This may be done using orthodox electrometer valve circuits, or a vibrating reed electrometer can be used. Both methods have their supporters.

A second and entirely different type of β-ray thickness gauge is the back-scattering type. In this form of gauge,

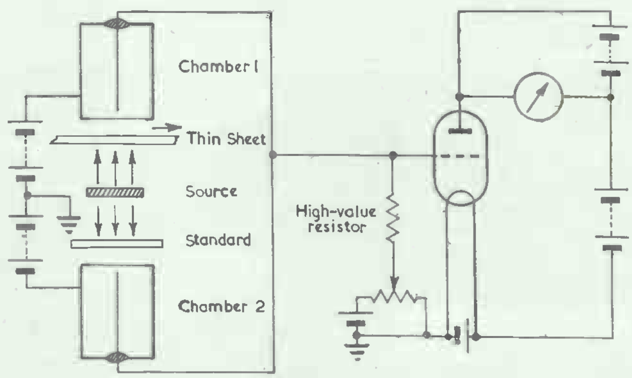


Fig. 2. Basic circuit for β-ray thickness gauge

the radiation scattered back from the sheet is measured instead of that which is transmitted. The main advantage of the back-scattering gauge is the possibility it confers of measuring coatings of one material on another. British manufacturers are now using this method in gauging tin coatings on steel and in gauging plastic or lacquer films on metal calenders.

Other Applications

The sorting of filled packages, canisters, etc., is another problem which may be solved using a nucleonic method. In this case, a γ-active source is placed on one side of the moving belt carrying the canisters, and a Geiger-counter detector is placed on the other side. The current in the output circuit of the counter depends on the filling of the canister, and any departure from the correct filling produces a change in this current value, which, in turn, causes a relay to operate and the diversion of the improperlyfilled unit. It is essential for uses of this kind to have a simple and reliable Geiger-counter detector. A suitable circuit for such a detector has been devised by E. H. Cooke-Yarborough[2]; it is shown in Fig. 3 and operates from the ordinary 230 volt A.C. mains. The counter is one of the new halogen-quenched counters described by E. Franklin and W. R. Loosemore[3] and now manufactured by Mullard Ltd., and 20th Century Electronics Ltd. These counters operate at a low-voltage (400 volts), have an almost infinite life, and are remarkably robust. As will be seen from the circuit the 230 volts mains are supplied to a Cockcroft and Walton multiplier to drive the Geiger counter. The cold-cathode tube triggered by the counter is also operated from this A.C. supply.

A further example, which illustrates the potentialities of radioactive materials has been described recently by E. W. Voice[4]. It is concerned with measuring the rate of wear of blast furnace linings. Attempts to get information by other methods on the rate at which the refractory lining is being worn away (or being added to) whilst the furnace is actually operating were unsuccessful. The radioactive method used by Voice consists in embedding some pellets containing radioactive cobalt (Co^{60}) in the refractory lining when the furnace is being built. The strength of the sources are made sufficiently strong to allow the presence of the pellets to be detected by surveying the outside of the

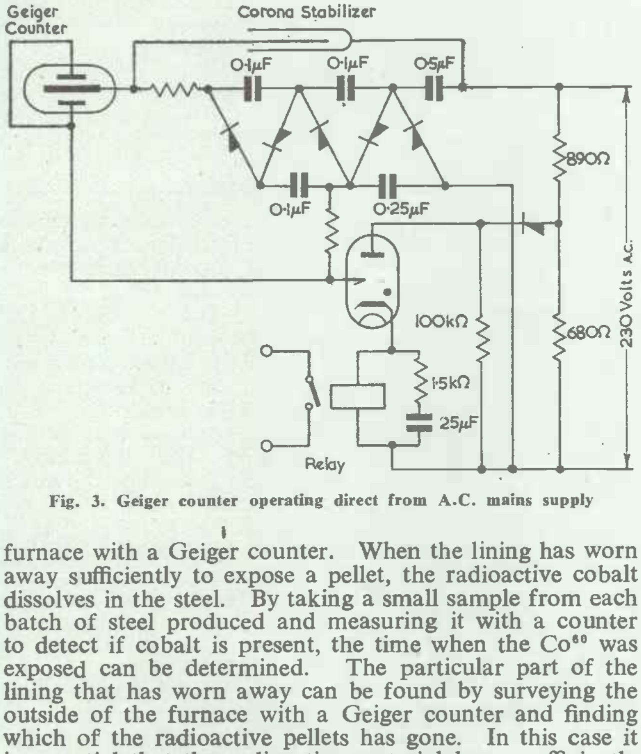


Fig. 3. Geiger counter operating direct from A.C. mains supply

furnace with a Geiger counter. When the lining has worn away sufficiently to expose a pellet, the radioactive cobalt dissolves in the steel. By taking a small sample from each batch of steel produced and measuring it with a counter to detect if cobalt is present, the time when the Co^{60} was exposed can be determined. The particular part of the lining that has worn away can be found by surveying the outside of the furnace with a Geiger counter and finding which of the radioactive pellets has gone. In this case it is essential that the radioactive material has a sufficiently long half-life to ensure that the radioactive pellets can still be detected after the furnace has been operating for many years.

Perhaps the most important application of radioactive materials is their use as "indicators" or "tracers." This use arises for two reasons, namely (i) that they emit a characteristic radiation which allows their presence to be detected even when present in very minute quantities, and (ii) that chemical processes and the majority of physical processes are largely insentitive to the small difference in weight which exists between the radioactive element and the corresponding stable (non-radioactive) element. It is thus possible to mix a small quantity of the radioactive element in question with the stable element and it will follow this material and behave in every way like it in chemical processes, etc., except in one respect—it will emit radiation which will betray its presence. Thus, radioactive iron (Fe^{55} and Fe^{59}) may be introduced into aero-engines and the amount appearing in the lubricating oil gives a measure of engine wear. In this way, it is possible to measure continuously how the rate of wear of any specific component in an engine varies with time without having to dismantle the engine to make the measurement. Another example of the same type which has been published by J. E. Johnston[5] is concerned with the rate of wear of dies used for extruding wire. He reports that J. W. Drinkwater and his co-workers at the Thornton Research Centre have studied the rate of wear of dies with the object of producing lubricants which will reduce the die wear to a minimum. For these experiments, the dies were made radioactive by irradiation in one of the A.E.R.E. atomic piles. When wire is drawn through the die a minute quantity of the die is carried away on the extruded wire. The amount and nature of the wear is found by placing the drawn wire in contact with a photographic plate for, say, 24 hours, and then removing and developing the plate. From the density of the blackening produced the amount of radioactive material on the wire is obtained. It is possible using this simple method to detect 3×10^{-10} gm/cm of the die on the extruded wire. Variations in the blackening produced on the photographic plate also show clearly whether the die wear is uniform, or whether it occurs in a series of jerks. If it is wished to measure the average rate of wear it may be more convenient to remove the surface of a long length of wire chemically and use a Geiger counter and counting-rate meter, or scaler to measure the amount of active material so removed. By analysing the type of radiation and the half-life of the radioactive material on the wire, it is also possible to see if there is any connexion between the method of wear and the constituents of the die. Examples of this tracer method can be multiplied many times, but sufficient has been written to make apparent the wide uses of nucleonics in industry and industry development.

Acknowledgment is made to the Director, A.E.R.E., for permission to publish this paper.

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ELECTRONIC STERILIZATION OF FOODS

A meeting was recently held at the D.S.I.R. to discuss the Electronic Sterilization of Pharmaceutical Products.

The possibility of using high velocity electrons for killing bacteria and other micro-organisms on a commercial scale has been investigated in the United States of America for several years, particularly regarding potential applications in the food and pharmaceutical industries. More recent developments have been concerned with the use of the radiations from radioactive atomic fission products, the waste products from atomic energy projects.

The main advantage of the process is that sterilization of a wide variety of products is possible, within severe practical limits, without the extensive damage associated with heat or chemical sterilization. Small amounts of chemical side effects occur which are frequently objectionable, but these can be reduced by suitable choice of technique.

A certain amount of work has been carried out in this country by the Food Investigation Organization of the D.S.I.R., with the co-operation of the Radiotherapeutic Research Unit of the Medical Research Council, at Hammersmith Hospital, mainly with the object of studying the effects on foods.

Beta-Particle and Gamma-Ray

Thickness Gauges

By M. G. Hammett*, M.I.E.E., A.M.I.Mech.E., and H. W. Finch*.

NOW that artificially produced radioactive isotopes are are readily available in large quantities, their use in industry has become a practical possibility. One of their widest fields of application would appear to be in those industries whose product is strip or sheet material. A need exists in these industries for a reliable method of measuring either the thickness of the sheet or of coatings applied to the sheet.

Many of the conventional methods of measuring thickness cannot be applied to thin sheet materials or are not capable of giving the desired accuracy because at the point of measurement the material may still be mechanically unstable.

Instruments are now available which depend for their action upon the absorption in matter of the radiations resulting from the decay of radioactive materials. The essential parts of such instruments are:

(a) A source of radiation,

(b) A detector of such radiations,

(c) An electronic amplifier and indicator.

The material to be measured is introduced between the source and the detector, neither of which need be in contact with the material. The signal at the detector is a function of the radiation falling upon it and this in turn depends upon the proportion of the radiation which is absorbed or dissipated in the material being measured. The proportion absorbed is dependent upon the mass of the material interposed between source and detector. If the detector output is calibrated against known thicknesses of the same material or if the density of the material is known, the final output may be directly calibrated in units of thickness.

The range of materials which have so far been successfully measured extends from paper less than 0·001in. thick of mass 1 milligramme per square centimetre (mgm/sq.cm) up to steel of mass exceeding 20 grams/sq.cm; any other materials within this range of mass may equally well be measured.

The accuracy obtainable depends upon a large number of factors which will be dealt with in the appropriate sections. Because the radiations are emitted randomly in time, the main controlling factor is the time allowable for the measurement, but an accuracy of 1 to 2 per cent is fairly easily attainable.

Sources of Radiation

The choice of the source of nuclear radiations for any particular measurement will depend upon the mass per unit area of the material to be measured. Materials of up to about 600 mg/sq.cm may be measured using β-particles. For thicker and more dense materials, it will be necessary to use either a γ-ray emitter or a source of X-rays.

When a table of the radioactive isotopes of the elements is examined it is found that relatively few of them are pure β-emitters. Of those that are, many have a half life that is too short to make them of use in an industrial application. Half life is defined as the time taken for the activity of a source to fall from a given value to half that value. If this time is of the order of days or weeks, the instrument will require frequent re-calibration. None of the long-lived naturally occurring radioactive isotopes are suitable pure β-emitters and some of the artificial (pile produced) isotopes that at first sight appear to be unattractive (because of their low energy and/or their short half life) are however very useful as they decay to a daughter product which has suitable characteristics.

In Table I are listed some of the possible isotopes that may be used in a β-ray thickness gauge.

TABLE 1

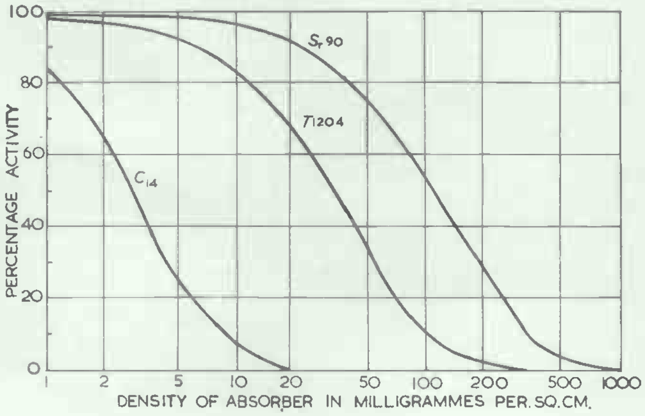
ISOTOPE	MAXIMUM ENERGY MeV	HALF LIFE	MAX. RANGE MILLIGRAMS/ SQ. CM.
Carbon (C^{14}) ..	0·145	5000 yrs.	20
Calcium (Ca^{45}) ..	0·26	80 days	45
Promethium (Pm^{147}) ..	0·22	4 yrs.	40
Strontium (Sr^{89}) ..	1·5	55 days	700
Strontium (Sr^{90}) ..	0·65	25 yrs.	230
Yttrium (Y^{90}) ..	2·5	62 hrs.	1200
Sulphur (S^{35}) ..	0·17	87 days	22
Thallium (Tl^{204}) ..	0·77	3 yrs.	300

Fig. I shows some typical shapes of absorption curves for some of the isotopes and in Table II figures are given that relate mass in milligrams per square centimetre to thickness for a number of common materials.

By reference to Tables 1 and 2 and to Fig. 1, the isotope suitable for a particular measurement may be selected. Experience shows that for maximum sensitivity and discrimination the mass per sq. cm. of the material to be measured should be as near as possible to the half thickness value of the isotope chosen, although there are differences of opinion on this point. Half thickness is defined as the thickness of absorber required to reduce the initial activity to half that value.

One other consideration in the choice of the isotope is its availability with a sufficiently high specific activity. Should the specific activity be low, a large mass of the element has to be used to obtain the required emission of β-particles, and to prevent undue self-absorption the isotope has to be laid down thinly over a large area.

Fig. 1. Absorption curves for carbon, thallium and strontium isotopes



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This inevitably means that a correspondingly large area of material must be measured from which it follows that the indicated thickness will be the integral taken over that area; this may be undesirable in certain applications. In addition the detector must have at least the same sensitive area; in some types of detector this is difficult to attain and in others will lead to a large and unwieldy measuring head.

Isotopes are used either as the pure chemical element

TABLE 2

THICKNESS		MASS IN MILLIGRAMS PER SQUARE CENTIMETRE					
In.	mm.	Paper	Card-board	Rub-ber	Alumin-ium	Brass	Steel
0·001	0·025	2·0	2·3	2·4	6·8	22	20
0·005	0·125	10	11·5	12·0	34	110	100
0·01	0·25	20	23	68	68	220	200
0·02	0·5	40	46	48	136	440	400
0·04	1·0	80	92	96	272	880	800
0·06	1·5	120	138	144	408	1320	1200
0·1	2·5	200	230	240	680	2200	2000
0·2	5·0	400	460	480	1360	4400	4000

or in the form of a stable chemical compound. They must be very firmly affixed, preferably by plating into a suitable source dish which should be of such a form that all health hazards are carefully guarded against even in the event of the holder being smashed or consumed by fire. Recommendations on these points may be obtained from the Isotopes Division, The Atomic Energy Research Establishment, Harwell.

For the measurement of very thick or dense materials which are beyond the range of β-particles, γ-rays or X-rays must be used. Unfortunately there are at present very few suitable γ emitting isotopes; because of their greater penetrating power the required energy in terms of electron volts is much lower in the case of the electro-magnetic radiations than for β-particles. The discovery that one of the isotopes of the element Thulium, emits γ-rays with an energy of 85keV may open up this field if more copious supplies of the element become available. At present its price is of the order of £100 per gramme and up to 2 grammes may be required in some cases. X-ray generators have been used for a number of years as sources for thickness measurements but their initial high cost and the complexity necessitated by the requirement of very stable beam currents of constant energy has prevented their general introduction. A great demand exists in the steel industry for an accurate gauge that may be applied to both hot and cold rolling mills and the development of a suitable simple X-ray generator capable of continuous operation under extremely arduous conditions is urgently awaited.

Radiation Detectors

Of the three common types of radiation detectors Geiger Muller tubes, Ionization Chambers and Scintillation Counters, the Ionization Chamber is the one most favoured in the majority of thickness gauges available commercially both in Great Britain and the U.S.A.

The Geiger Muller tube has the great advantage of simplicity and great sensitivity but because of its limited counting rate and the statistical variations in the rate of emission of the radiations, the time required for a precise measurement is too long in most cases and because of its many vagaries it cannot, except by a skilled user, be regarded as a precise detector. The Scintillation Counter has been widely investigated in the last year or two and its introduction in the industrial field may soon be expected, particularly as the detector for γ-ray thickness gauges where its very high counting efficiency will make it particularly useful.

An ionization chamber consists essentially of two electrodes, enclosed in a gas-filled chamber and maintained at a potential difference of a few hundred volts. The ionization produced by the radiation falling upon the gas in the chamber causes conduction between the two electrodes. With increasing voltage between the two electrodes the ion current first increases, then as the voltage is increased still further the current eventually reaches a constant value (the saturation current) which is a direct measure of the rate of production of charged ions in the gas volume and thus of the radiation falling upon the chamber.

In a practical ionization chamber, one electrode is formed by the outer wall of the chamber and the other by a central tube electrode insulated from the outer wall via a guard ring to prevent direct leakage. Part of the outer wall is made very thin to permit the entry of β-particles with as small a loss of energy as possible. The whole assembly is sealed and filled with dry air at a

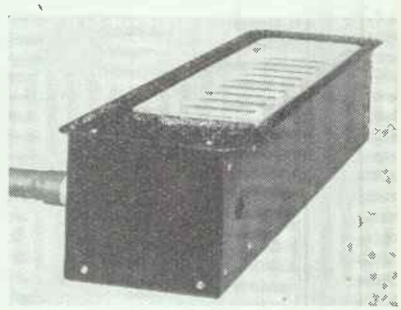

Fig. 2. A typical ionization chamber

pressure slightly different from normal atmospheric pressure to pre-stress the thin "window" in the outer wall and to maintain the geometry of the system constant. The configuration of the two electrodes should be such that the voltage gradient between them is as nearly uniform as possible over the whole of the chamber volume in order to ensure that the chamber is working on the "saturation current" part of its characteristic. The ionization current produced is directly proportional to the mass of the gas in the chamber; to maintain the current and hence the calibration, constant the chamber must be completely sealed. At the same time the "window" must

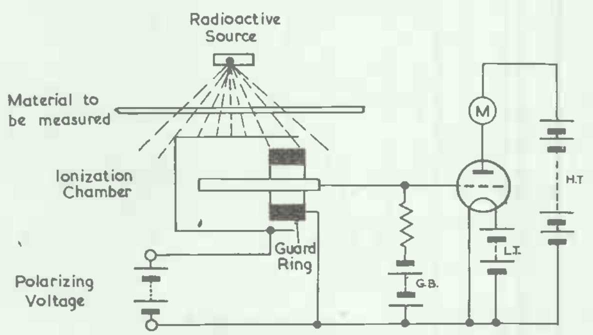

Fig. 3. Simple ionization indicator circuit

be of as low a mass as possible to prevent it becoming an appreciable fraction of the total absorber in the path of the radiation and thus decreasing the discrimination of the instrument to small changes in thickness of the material being measured. In addition the "window" must be electrically conducting to maintain a uniform field in the chamber. All these factors together result in the choice of aluminium foil about 0·001in. thick for the chamber window. The main chamber body may conveniently consist of an impregnated light-alloy casting and the window and guard rings may be sealed to it by means of low compression-set rubber. Fig. 2 shows a typical ionization chamber.

The polarizing potential required for this chamber is between 150 and 200 volts and may be connected so that the outer case is positive or negative according to the required polarity of the output current. The current produced in the chamber is $1{\cdot}6 \times 10^{-19}$ times the number of ion pairs and for thickness gauge purposes the mean current is usually arranged to be between 10^{-11} and 10^{-9} Amperes.

The Amplifier and Indicator

The simplest form of indicator for an ionzation chamber instrument consists of an electrometer valve operated with a very high value grid resistor. The ionization chamber output is connected directly across the grid resistor and a meter in the anode circuit may be directly calibrated in thickness units for a given material. This arrangement, shown in Fig. 3, is adequate for rough measurements but its long term stability is very poor.

D.C. Amplifiers with negative feedback, again using an electrometer valve at the input, show a considerable improvement over the simple arrangement described but are not completely suitable for the highest precision measurements under industrial conditions because of the difficulty of maintaining the long-term stability, in terms of input voltage, to better than 10 or 20 millivolts. The following will indicate the degree of stability required in measuring, for example, material of mass 2 milligrams per square centimetre to an accuracy of 2 per cent.

Mass of protective covering over source	14	mgm/sq.cm.
Mass of window in chamber	10	„
Mass of air in source-chamber gap of 2 in.	6	„
Material to be measured	2	„
Total ..	32	„
2 per cent change in material ..	0.04	mgm/sq.cm.
Fractional change in total ..	1/800	

This is further aggravated by the fact that the slope of the curve of ionization current versus mass of absorber is not constant and decreases considerably at each end of the absorption range for a particular isotope. Because of this, the fractional change of total absorber of one part in eight hundred may result in a change in ionization current of only one part in a few thousand. It follows from this that the stability of the amplifier and indicator must be extremely high.

A simple Vibrating Reed Electrometer may easily be made to have a long-term stability of 1 millivolt and with care may be as good as 100 microvolts. But, given even this order of stability, it is still difficult to make a direct reading instrument with a discrimination of one part in a few thousand.

Fig. 4 shows a schematic diagram of one type of instrument that has given reliable service for a wide range of measurements. By the use of the balanced system many errors are eliminated and the sensitivity of the system to small changes in thickness considerably increased. Provided the two sources are of the same isotope and the system is initially balanced with a piece of material of mean thickness between each of the sources and chambers, the decay of the isotope affects only the sensitivity of the instrument, which is easily corrected by periodic adjustment of the sensitivity control, and not its absolute accuracy. When measuring very thin materials the air in the gap between source and chamber may easily have a greater mass than the material being measured and changes in ambient temperature will show up as apparent large changes in thickness. With the two-channel system this effect may be largely eliminated by ensuring that the two air gaps are similar and suffer the same temperature changes.

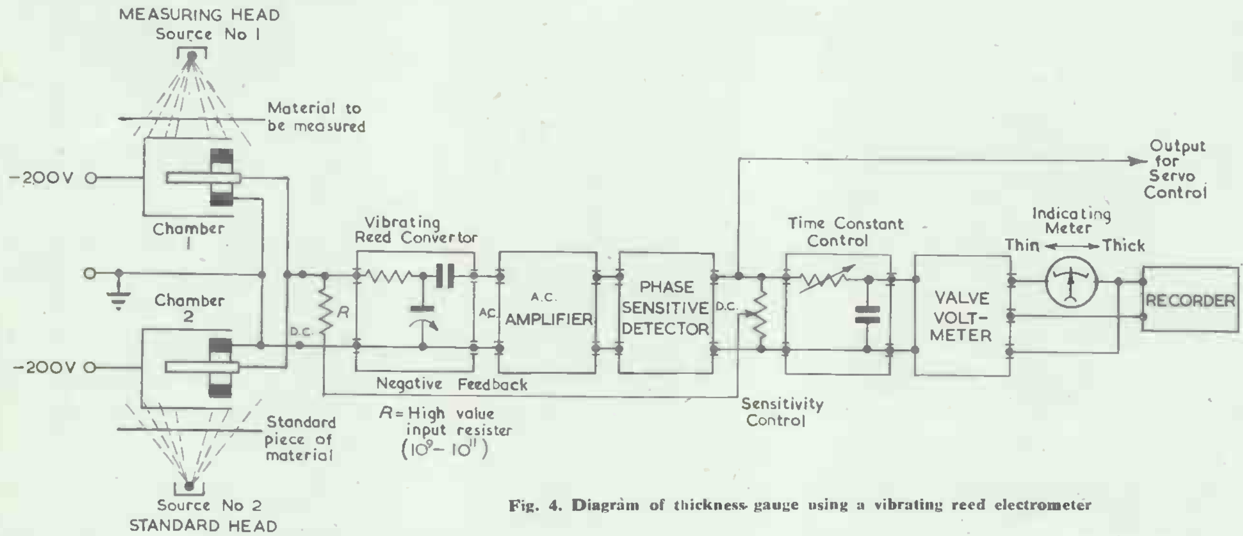

Fig. 4. Diagram of thickness gauge using a vibrating reed electrometer

Where only a single-channel system is used the input voltage and hence the final indication of thickness is directly proportional to the product of the ionization current and the value of the input resistor. Input resistors of the required high value have an appreciable temperature coefficient and variations will show up as direct thickness changes. In the balanced system only the sensitivity is affected; where very high long-term accuracy is required, the resistor must be kept in a thermostatically controlled oven held at a temperature higher than the highest expected ambient temperature.

By the application of overall negative feedback as shown in Fig. 4 variations in the gain of the amplifier, the sensitivity of the detector and the conversion efficiency of the D.C. to A.C. converter may be reduced to negligible proportions and for all practical purposes both long and short term variations in the electronics of the system may be ignored. In some measurements a mean value of thickness along the length of the material is required and the fluctuation of the needle of the output meter may be eliminated by adjustment of the "time-constant" control. This control is also useful when measuring very thin materials or materials near the maximum range of the particular isotope when the random nature of the emission shows up more and limits the short term accuracy of measurement.

A voltage output is available which may be used for automatic control of the thickness of the material being produced. An alternative output to which a recorder may be connected is also a useful adjunct as in many cases a permanent record of the thickness of the product has been found desirable.

Installation

The fitting of a gauge to a particular machine has been found to be relatively easy, but each installation has to be treated on its merits and the necessary mounting arrangements have to be tailored to suit individual requirements. These have to be very rigid and must be arranged to maintain the spacing between the source holder and the measuring chamber constant to within 0·005-0·01in. if accurate results are to be obtained. A spring-loaded cover should be fitted to the source tray to prevent stray radiation reaching workers when no material is in the gap.

When a measurement is required of thickness variations across the width of a sheet of material, two alternatives are available. The source and chamber may be scanned together across the sheet, provided that their relative geometry is maintained constant or alternatively a number of discrete measuring points may be used all balanced against one "standard head" and sequentially switched either manually or mechanically. In all installations care must be taken to ensure that the position of the measured material does not vary unduly in the source-chamber gap. Variations of position will change the average number of scattered electrons reaching the chamber and will result in a change in indicated thickness. This effect may be reduced, at the expense of sensitivity, by arranging collimating plates in front of both the source and chamber to ensure that only those electrons following a track normal to the surface of the material are concerned in the measurement.

In some cases a measurement is required of a coating on a base material which is itself not uniform. This may be achieved by passing the uncoated material through the "standard head" to which has been fitted a permanent absorber representative of the mean coating thickness, and then passing the coated material through the "measuring head." Provided that there is no rapid change in the thickness of the base material between the two points of measurement, the gauge will then indicate variations between the actual coating thickness and the selected standard.

By arranging for the spacing between the source and chamber in the "standard head" to be adjusted and thus varying the geometry of the system, slight differences in the strengths of the two sources may be compensated. Alternatively slight changes may be simulated in the piece of standard material when it is required to measure a short range of thicknesses differing by only small amounts without the necessity for maintaining a number of standards.

Applications

As has been mentioned previously, the main uses of this type of thickness gauge are in those industries in which the product is in the form of thin sheet material. Table III shows the possible overall accuracies when used for these applications.

Laboratory experiments show that similar results should be obtainable when the field is extended to thicker sheet materials by the use of suitable γ sources or X-ray generators. Care must be taken in all cases, and more particularly when γ-rays and X-rays are used as the source of radiation, to guard against erroneous readings due to the inclusion of fillers of high atomic number. This is achieved by always using a comparison standard of the same chemical composition as the material being measured. Measurement of a material before it is fully dry will also lead to false readings unless allowance is made for this.

In some cases the fact that this type of instrument measures mass per unit area and not true thickness may be turned to advantage by using it to measure a product that is sold by weight. One instance of this is the use of a gauge to weigh cigarettes and in this case the error signal is used to correct the machine automatically. This has resulted in a more uniform product and a significant saving of tobacco by enabling the minimum weight to be more closely approached; this application is typical of the saving that may follow the use of this type of gauge.

Simple γ-ray gauges have been used as "go"-"no-go" gauges to check the correct internal assemblies of such objects as shell fuses where visual examination cannot be carried out and radiography would take too long.

All the foregoing applications have relied upon the presentation to the gauge of a constant area of the material for measurement. Provided that the material is sufficiently thick or dense to stop all the radiations the gauge may be used as a "sizing" gauge by measuring the radiation that passes round the sides of an object.

A further application of the instrument is its use as a reflexion type of gauge. In this case the fact is utilized that a significant number of the β-particles falling on a piece of material may be reflected, that is, deflected through more than 90°. The intensity of the back-scattering increases with increase in the atomic number of the material. By making use of this phenomenon the thickness may be measured of thin coatings on thick base materials provided that (a) the two materials have different atomic numbers, (b) the base material is thicker than 1/5th the maximum range of the β-particles. In this method of use the source and detector are placed on the same side of the material, but screened from one another. Coatings of tin on steel sheet and of plastic material on steel callendar rolls have been measured in this way. This method of use suffers from numerous disadvantages probably the greatest of which is the poor efficiency; only some 10 per cent of the incident β-particles are reflected, and to obtain similar detector currents to those obtained in the transmission method, sources of much higher activity must in general be used.

TABLE 3

MATERIAL	THICKNESS FOR MEASUREMENT ACCURACY 1 PER CENT		
	Time Constant 0·2 secs.	Time Constant 2 secs.	Time Constant 20 secs.
	in.	in.	in.
Paper and Plastics	0·0075–0·0165	0·0045–0·165	0·001–0·165
Aluminium	0·003 –0·075	0·002 –0·075	0·005–0·075
Ferrous metals, Brass, Copper, Zinc	0·001 –0·022	0·0006–0·022	0·0002–0·022

Only a few of the numerous possible applications have been mentioned herein. Entirely satisfactory solutions have not yet been found to a number of current problems and new proposals for the use of this type of instrument are being made almost daily.

There is no doubt whatever that Radiation type Thickness Gauges already have a very important place in the field of industrial process control and their scope will undoubtedly be greatly extended in the future.

Acknowledgment

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Electron Tubes
for
Industry and Research

By C. C. Gee*

During recent years such outstanding advances have been made in the development of electron tubes that it is becoming increasingly difficult to distinguish between the class and function of the great variety of types which are now available. In this article and the accompanying charts an attempt is made to show the relationship that exists between the various groups of electron tubes and to indicate the more important of their applications in industrial electronic equipment and research.

Electronics may be defined as that branch of physics or electrical engineering which relates to the conduction and control of electricity in vacua and gases. Since this almost invariably involves the flow of free electrons in some form of electron tube, electronics is sometimes alternatively described as the branch of science and technology that involves the use of electron tubes.† In this context the electron tube is a generic name which includes thermionic valves, cathode ray tubes, photocells—in fact, any vacuum or gaseous device that depends for its action upon the control of the motion of free electrons or other charged particles.

In a broad sense, therefore, the term electron tube includes particle-accelerating devices such as the cyclotron, the betatron and the linear accelerator. The design and applications of these devices, however, are so highly specialized that they are usually regarded as coming strictly within the province of the even newer branch of science, nuclear physics.

It may also be argued on technical grounds that, since fluorescent lamps and other high intensity discharge lighting sources also function by virtue of the flow of charged particles in gases at controlled pressure, they too come within the general category of electron tubes. The distinction between the two classes of device is indeed difficult to define, except by stating that whereas precise control of the flow of free electrons and other charged particles is fundamental to the operation of electron tubes, it is only of secondary importance to the operation of discharge devices used as continuous light sources.

The contribution made by developments in electron tubes to the progress of telecommunications, television and radar is already universally recognized. But what is perhaps not so widely realized is the important contributions that improvements in the design and performance of electron tubes, and the development of many entirely new types, are making to the applications of electronics in industry and research.

In view of the great variety of electron tubes that is now available for such applications, the problem of selecting the most suitable type for any particular purpose is becoming increasingly difficult. Reference to the accompanying charts will, however, show that, in spite of the extensive range of electron tubes which are available, they can be conveniently sub-divided into a comparatively small number of fairly distinct groups.

The method of classification adopted here is based on the fact that electron tubes, whatever their form, employ one basic principle—the release of a stream of free electrons, which, suitably controlled or modified, can be used to perform a wide variety of functions. The methods of releasing electrons, in order of importance, are as follows :—

* Mullard Ltd.

1. Thermionic Emission

This refers to the release of electrons from certain metals or metallic oxides through the action of heat.

2. Photo-emission

This relates to the liberation of electrons from certain metals or metallic compounds when subjected to the influence of light or other radiation of sufficiently short wavelength, i.e. infra-red and ultra-violet radiation.

3. Ionic Bombardment

This refers to the ejection of electrons from a solid due to bombardment by ions. (In electron tubes, the ejection of electrons from metalic electrodes due to bombardment by primary electrons from the cathode is usually referred to as "secondary emission" or "electron multiplication").

4. Ionization or Gas Amplification

This relates to the release of electrons through the collision of electrons with isolated gas molecules. This leaves the molecule ionized with a positive charge.

5. Field Emission

This refers to the liberation of electrons from cold metals by virtue of a very high potential gradient at the surface of the metal.

6. Radioactive Disintegration

This refers to the ejection of electrons (beta radiation) during the slow process of disintegration of radioactive substances.

It is only the first three of these methods which provide primary sources of electrons for the operation of electron tubes. It is upon the basis of these that the classification of electron tubes has been founded. In some of the tubes gas amplification and secondary emission may, in addition, be employed to increase the stream of electrons. But so far as the classification is concerned, these have been regarded as secondary effects.

It will be seen from the charts that the three main classes of electron tube are divided into six fairly distinct groups. These are as follows :—

1. Thermionic Valves.
2. Cathode-Ray Tubes and Associated Devices.
3. Arc-action Gas-filled Tubes and Devices.
4. X-Ray Tubes.
5. Photo-electric Devices.
6. Cold-Cathode Tubes.

For sake of completeness, a miscellaneous group has been embodied which includes such highly specialized devices as the electron microscope and particle accelerators.

† *Research in recent years has shown that free electrons in certain substances known as semi-conductors can be controlled much in the same way as they can in electron tubes. Semi-conductors, in the form of crystal diodes are, in fact, finding application in certain compact communications equipment and computors, whilst numerous applications have been suggested for crystal triodes or transistors. It is not the intention here to enter into the controversy as to whether or not semi-conductors may be regarded as truly electronic elements. It is certainly much too early yet to assess, with any degree of reliability, how far they are likely in the future to complement electron tubes as fundamental elements in electronic circuits.*

CLASSIFICATION OF ELECTRON TUBES FOR INDUSTRY AND RESEARCH

Primary Physical Effect	No.	Group	No.	Sub-Group		Principal Applications
Thermionic Emission	1	Thermionic Valves	1	Low-Power Valves	Two-electrode Valves or Diodes	Power rectification in supply units and signal rectification or detection and frequency mixing in electronic instruments. High voltage types also widely used for supplying direct voltages up to and beyond 100kV to X-ray tubes, electrostatic precipitators etc.
					Multi-electrode Valves (Triodes, Tetrodes, Pentodes, etc.)	Used for voltage and power amplification, signal detection, modulation and frequency mixing. Also used in multi-stable state networks for computing.
			2	High-Power Valves	Multi-electrode Valves (Triodes, Tetrodes, Pentodes, etc.)	Silica, Hard-glass, Forced-air and Water-cooled types available for voltage and power generation and amplification, etc., in transmitters, R.F. heating equipments, ultrasonic generators. (Diodes are also used in certain high-voltage, high-power supply units).
			3	Special Valves	Electrometer Valves	Amplification of voltages from very high impedance sources. Widely used in *p*H meters, valve voltmeters, and radiation meters. May also be used with photocells and ionization chambers. Can be used for detecting and amplifying currents as low as 10^{-15} A.
					Secondary Emission Amplifiers	Applications limited to photomultipliers and broad-band amplifiers where high slope and low capacitance are important. Find use in broad-band oscilloscopes for research and industrial investigations.
					Noise Diodes	Provide a standard noise source to which unknown sound sources can be referred.
					Saturated (Tungsten) Diodes	Used as a sampling element in low-voltage control circuits, e.g., filament circuits.
					Accelerometer Valves	May be used for the measurement and recording of accelerations, vibration and very small angular displacements.
			4	U.H.F. or Microwave Tubes	Disk-Seal Valves	May be used for power or pulse generation and signal rectification and amplification in transmitting and radar systems operating on wavelengths down to 10cm.
					Velocity - modulated Valves (Klystrons ; Reflex Klystrons ; C.Z. Tubes ; Heil Tubes)	Power generation in microwave pulse and F.M. systems, e.g., radar and communication networks. Amplification also possible with amplifier klystrons.
					Travelling Wave Tubes	Signal generation and amplification in microwave systems.
					Magnetrons	Used as medium and high-powered pulsed oscillators in microwave systems, i.e., radar, linear accelerators, etc. Also available as lower-power generators in C.W. systems.
	2	Cathode-Ray Tubes and Associated Devices	1	Instrument Cathode-Ray Tubes		Widely used in oscilloscopes and as indicating and measuring devices in instruments.
			2	Radar Display Tubes		P.P.I. and 'A' Scan displays in radar systems.
			3	Television Picture Tubes		Direct-viewing and projection television equipment.
			4	Special Tubes	Indicator Tubes (Magic Eyes)	Used as tuning indicators, or as null indicators in measuring instruments.
					Digital Computor Storage Tubes	Used as memory elements in complex electronic computing machines.
					Beam Switches, Counting Tubes, and Frequency Multiplying Devices, with or without secondary emission	Used in scaling and counting circuits, and for frequency stabilization.

Primary Physical Effect	No.	Group	No.	Sub-Group		Principal Applications
Thermionic Emission (cont'd)	2	Cathode-Ray Tubes and Associated Devices	4	Special Tubes	Skiatrons	May be used as display tubes in radar systems.
					Flying-Spot Scanning Tubes	Flying-spot scanning for the television transmission of films, maps, writing, etc. Also used in the flying-spot microscope.
	3	Arc-Action, Gas-filled Tubes and Devices	1	Industrial Rectifiers	Mercury Vapour Rectifiers	High power rectification in telecommunications and industrial equipment, e.g., transmitters, sound amplifiers, R.F. heating equipment and ultrasonic generators.
					Xenon-filled Rectifiers	Used for power rectification purposes in aircraft, ships and other situations where vibration and varying ambient temperatures are liable to be encountered.
					Argon-filled Rectifiers (Rectigons and Tungars)	Low voltage rectification. Used for charging storage batteries and supplying direct current for arc lamps in cinema projectors.
			2	Thyratrons	Mercury Vapour Thyratrons	Grid-controlled rectification. Widely used in high-speed power switching, motor control, lighting control, spot welding control and voltage regulation systems.
					Rare-Gas Thyratrons	Widely used in high-speed timers, relays, counters and lower-power motor control systems, in servo-mechanism systems, in situations, e.g., aircraft and ships—where vibration and varying ambient temperatures are liable to be encountered, and where high peak-to-mean ratios of current are of importance.
					Hydrogen Thyratrons	Pulse modulators in radar systems. Also used for the production of high-power microsecond pulses for precision triggering applications, e.g., grid-controlled image convertors.
			3	Mercury-pool Cathode Devices (Ignitrons, Exitrons, Senditrons, Mercury-pool Rectifiers)		Rectification, conversion and the control of large amounts of power. Ignitrons, in particular, are widely used for high-power resistance welding control and very high-power motor control.
	4	X-ray Tubes	1	Industrial and Scientific Tubes	Inspection Tubes	Tubes with voltages of up to 300kV available for the radiographic examination of castings, the inspection of welding joints, the flouroscopic inspection of foodstuffs, etc.
					Diffraction Tubes	Tubes available from 30kV to 260kV for the treatment of cancer and other growths.
			2	Medical Tubes	Diagnostic Tubes	Stationary and rotating anode tubes available of up to 125kV for the examination of parts of the body.
					Therapy Tubes	Tubes available of up to 260kV for the treatment of cancer and other growths.
Photo-Emission	5	Photo-Electric Devices	1	Photocells	Vacuum Photocells	Measurement and control applications where changes in light may be small and gradual, e.g., comparison by colour ; and in viscosity, register, positioning and tensioning controls.
					Gas-filled Photocells	Applications where the changes in light are large and sudden, or where high amplifications are required. Used widely in "on-off" or "stop-go" devices, e.g., warning and burglar alarms, protection systems, counters, etc. Also extensively used in sound-on-film equipment.
			2	Photo-multipliers		Measurement and detection of very low light levels as encountered in scintillation counting, pyrometry, spectrometry and astrophysics.
			3	Image Convertors		Conversion of infra-red and ultra-violet radiation to radiation in the visible spectrum. May also be used as a very high-speed camera and/or stroboscope for studying ultra high-speed phenomena.
			4	Image Intensifiers		May be used to increase the brilliance and contrast of objects to facilitate examination, e.g., radiographs.

Primary Physical Effect	No.	Group	No.	Sub-Group		Principal Applications
Photo Emission (cont'd)	5	Photo-Electric Devices	5	Camera or Pick-up Tubes (Iconoscopes, Super Iconoscopes, Orthicons, Image Orthicons, C.P.S. Tubes and Monoscopes)		Used for image dissection and generation of television picture signals. The low-velocity types, incorporating secondary emission, give the highest sensitivity.
Ionic Bombardment	6	Cold-Cathode Tubes	1	Voltage Stabilizers		Stabilization of voltage in power supplies.
			2	Voltage Reference Tubes		Provide a very accurate reference voltage for use in laboratory and industrial measuring apparatus. May be used to replace Standard Cells or H.T. batteries in reference level power supplies. Can also be used as a stable source of voltage for comparing or fixing the levels of physical quantities under investigation, e.g., *p*H, level, speed, etc.
			3	Rectifier Diodes		High voltage rectification.
			4	Trigger Tubes (Cold Cathode Thyratrons)		Widely used in scaling and counting circuits, industrial timers, alarm and protection circuits, etc. May also be used for remote-controlled switching over power lines and as a semi-electrometer with photocells and ionization devices.
			5	Rare-Gas Cartridges		Used for protecting aerials, telephones, telegraph and power lines and other apparatus from the effects of static charges, lightning, short-circuits and other surges.
			6	Multi-position Stepping Tubes		Used in computing and scaling circuits. Also used for frequency division and as a memory device.
			7	Arc Tubes (Neostrons)		Used as a stroboscopic light source and can be operated at frequencies up to 250c/s. May also be used as a modulator for echo-sounding equipment.
			8	Electronic Flash Tubes		Primarily used as a source of illumination for high-speed photography. May also be used as a stroboscopic light source.
			9	Geiger-Müller Counters		Detection of ionizing radiations, i.e., alpha, beta, gamma radiation, X-rays, etc.
			10	T. R. Switches		Used in radar and similar systems for short-circuiting the very sensitive receiver when the associated high-power transmitter is operating.
Various	7	Miscellaneous	1	Ionization Chambers		Detection of ionizing radiations, i.e., alpha, beta, gamma radiation.
			2	Vacuum Gauges		Pirani, Penning and ionization gauges available for measuring vacua at low and very low pressures over the range of 1mm down to 10^{-8} mm Hg. Ionization gauges give the highest sensitivity.
			3	Hot-Cathode Ion Emission Tubes		The detection of very small proportions of halogen gas in air. Used for detecting leaks in refrigeration plants, etc. Also used for detecting porosity and cracks in welds.
			4	Electron Microscopes		Provides a means of increasing the magnification of the optical microscope by over a 100 times. Proving an important tool in physical, chemical and biological research.
			5	Particle Acceleration Devices	Cascade Generators	Suitable for accelerating electrons and ions. Practical energy limit 1–2½MeV. Generators of the impulse type have been built, giving energies of up to 3·2MeV. Used in nuclear physics research and for radiation therapy.
					Van de Graaf Generators	Suitable for accelerating electrons and ions. Practical energy limit 4–5MeV. Used for research in nuclear physics and for radiation therapy.
					Capacitrons	Suitable for accelerating electrons and ions. Practical energy limit 3–4MeV. Have been mainly used for research work on the sterlization of foods.

Primary Physical Effect	No.	Group	No.	Sub-Group		Principal Applications
Various (cont'd)	7	Miscel-laneous	5	Particle Accelerat-ing Devices	Cyclotrons	Suitable for accelerating protons, deuterons and alpha particles. Practical energy limit about 20MeV for deuterons or 40MeV for alpha particles. Energy limit set by relativistic increase of particle mass. This limitation is to a considerable extent overcome in the synchrocyclotron or frequency-modulated cyclotron. With these machines proton energies of well over 300MeV have so far been obtained. Cyclotrons are particularly valuable in nuclear research for creating and studying the effects of nuclear fission.
					Synchrotrons	The synchroton principle can be used for accelerating electrons and protrons. The practical energy limit of the electron synchrotron is about 1000MeV. With the proton synchrotron it should be possible to produce energies of several thousand MeV. In nuclear physics synchrotrons are of great value for studying photo-disintegrations of λ-rays. They also have use in medical research as a high-energy x-ray source for therapy.
					Betatrons	Suitable for accelerating electrons. Practical energy limit about 300MeV. Used in nuclear physics for studying photo-disintegration effects ; in medicine for radiation therapy ; and in industry for radiography.
					Microtrons	Suitable for accelerating electrons. One or two machines have been produced giving energies between 4 and 5MeV. The beam currents obtained are very low.
					Linear Accelerators	Suitable for accelerating electrons in bursts of very short duration. Has the advantage that extremely high beam currents can be obtained. Proving extremely valuable as a neutron source for measurement work in nuclear physics research. Also provides a very economical means of producing high voltage x-rays for deep-seated therapy and for industrial radiography. Commercial machines are capable of producing up to 15MeV. It should be possible to produce machines giving energies in the region of 1000MeV and over. The linear accelerator can also be used for accelerating ions and a 20MeV machine has been constructed.

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COUNTING AND SIZING OF PARTICLES

The counting and size distribution of fine particles deposited at random is a task which has to be undertaken in many branches of research and industry, and an accurate assessment of precipitation is essential in such problems as atmospheric pollution by large power stations, insecticide spraying and dust precipitation in coal mines.

A counting and sizing apparatus for this purpose has been developed by the National Institute of Agricultural Engineering in conjunction with the Research Branch of the Post Office Engineering Department and was displayed at the N.I.A.E. Open Day at Silsoe, Beds., earlier this year. The complete apparatus (shown in the photograph) employs a scanning technique known as the intercept length method and consists essentially of a Muirhead facsimile transmitter and a pulse width analyser counter circuit incorporating dekatrons.

A paper stained by spray droplets forms the sample area and is scanned by the facsimile transmitter in 10-15 minutes. The electrical output from the transmitter is fed into the pulse width analyser which gives a total count and a count of the number of particles in the various size groups.