Electronic Engineering

INCORPORATING ELECTRONICS, TELEVISION AND SHORT WAVE WORLD

PRINCIPAL CONTENTS

2/- JULY, 1945

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Says Robert F. Six

PRESIDENT, CONTINENTAL AIR LINES

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Denver, Colorado

January 9, 1945

Chief Engineer
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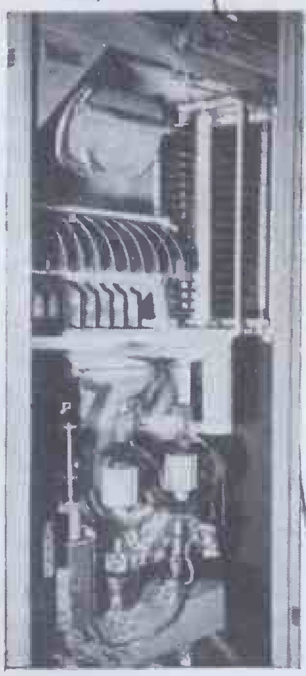

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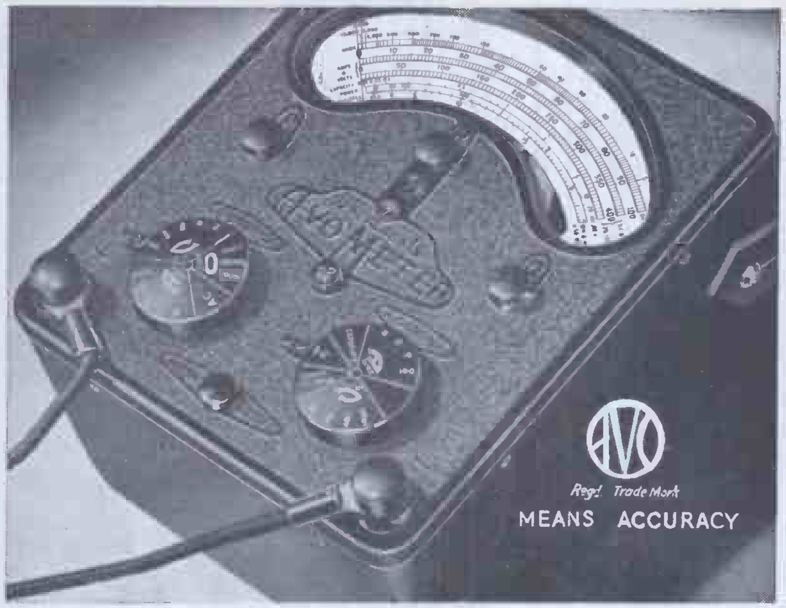

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CONTENTS

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Applied Physics

THE question of whether physics or electrical engineering is the parent of electronics is occasionally debated without much conviction. It would be a satisfactory compromise to say that electronics was bred out of electrical engineering by physics, and the offspring favours one parent or the other depending on its ultimate career.

For certain branches of electronics, such as, for example, X-ray research, a background training of physics to a higher degree than that usually given by engineering courses is essential. On the other hand, in the application of electronics to heavy industry a knowledge of electrical engineering will provide a better basis on which to discuss processes and circuit problems.

Whichever branch of electronics the student intends to take up, there is no doubt that applied physics has not received the attention in training curricula to which its importance entitles it, and for this reason the Institute of Physics pressed recently for an award of a Higher National Certificate in Applied Physics.

With the rapid growth of physics in industry and in the different Government services, it has been found that the existing courses in branches of engineering, in chemistry and so on, do not singly provide the combination of knowledge required in some branches of work, such as, for example, the physical testing of materials, and the maintenance and use of instruments for the measurement and control of processes.*

The new H.N.C. course announced by the Ministry of Education follows on the course for the Ordinary National Certificate, which is a three-year part-time one. This includes Mathematics, Physics and Chemistry and a special course in Workshop Practice and Drawing. Students are also encouraged in the writing of clear and concise reports.

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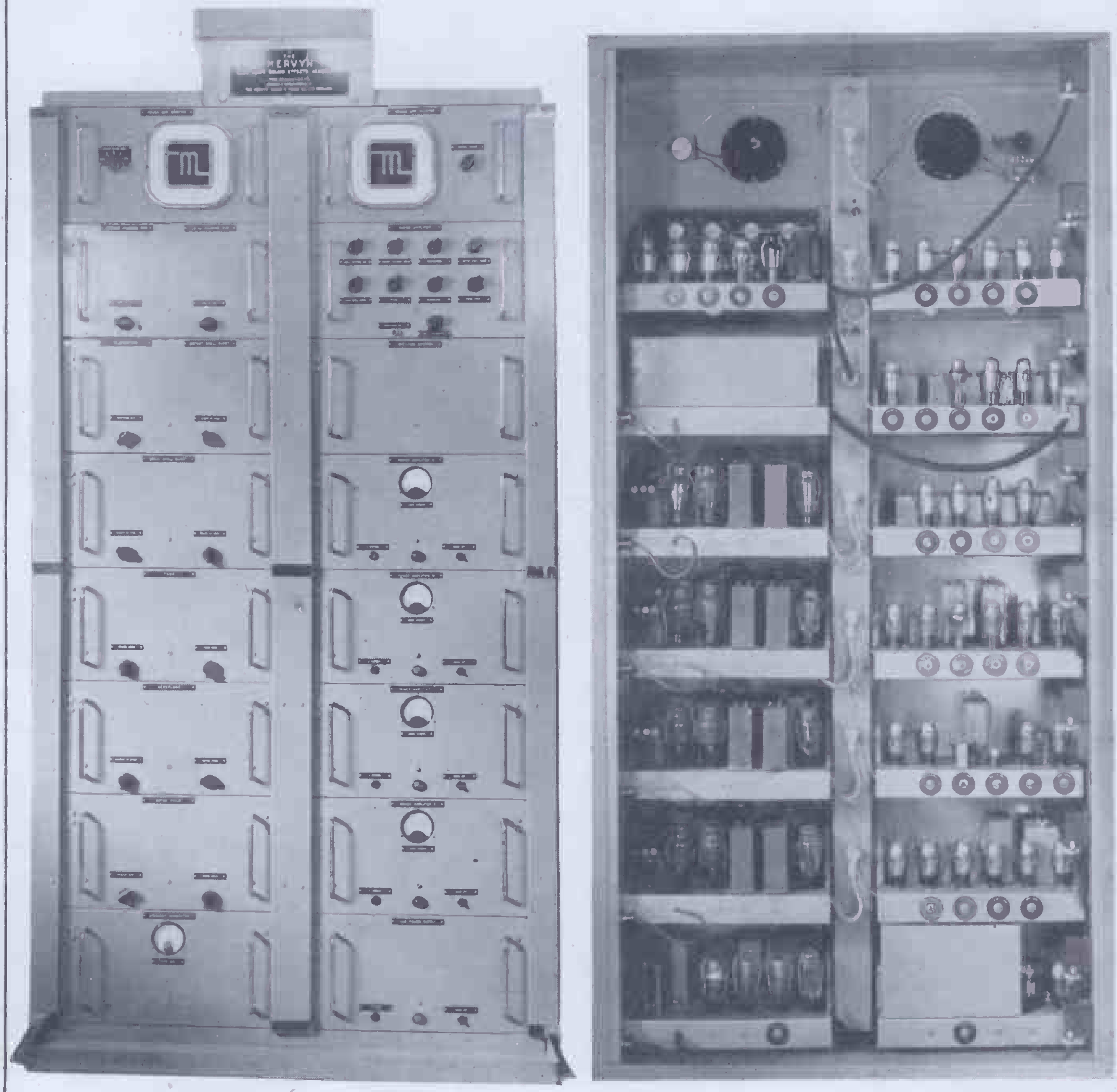
Electronic Sound Effects Generator



Front and back views of the electronic generator described in the accompanying article. The panels on the left control individual sound effects, and the power amplifiers and mixer panel are on the right.

Electronic Sound Effects

Equipment for the Production of Sounds by Purely Electronic Means

By P. D. SAW*

Introduction

DURING the war years many highly technical methods have been developed for the training of Service personnel, and the use of appropriate sound effects has in no small measure increased the efficiency and realism of these battle training courses. The production of sound for this purpose has been accomplished in various ways, including disk recording, sound tracks on film, and purely mechanical methods; but in this article it is only proposed to describe a system which has been developed for the production of sound effects by purely electronic means.

The idea was first conceived several years ago when the need arose for sound equipment to be incorporated in certain Naval training establishments, where specified effects were required to occur in synchronism with other events, and since these events were to take place at indefinite intervals it would not have been practical to utilise ordinary sound recordings for this application.

Accordingly a method was developed for producing the necessary waveforms by electronic means, so that they could be readily controlled in conjunction with other operations in the training schedule. At the same time other sound effects, required to operate more or less continuously and therefore suitable for production by orthodox methods, were also generated electronically and incorporated in the equipment for general convenience.

As a result of experience gained in this specialised field the development of a more elaborate sound effects generator was undertaken, for use at an Army training centre, and this particular equipment, illustrated by photographs accompanying the article, will now be described in some detail.

General Description

The complete equipment comprises 16 separate panels mounted on a double rack of standard width and arranged so that any unit may be removed from the front after disconnecting the appropriate plugs. Eight of these panels are involved in the actual generation of the sound effects: four panels carry the power amplifiers, and the remaining four panels include the mixing amplifier, the auxiliary power supply, and two monitoring loudspeakers—one working from the mixing amplifier directly, and the other used for checking the output from the power amplifiers.

The above forms a complete unit in that the only external connexions required are for the A.C. mains input and external loudspeakers. Sockets are provided at the side of the rack for plugging in any number of loudspeakers up to 32, and the maximum power output obtainable is approximately 200 watts.

The apparatus is entirely automatic in action and once switched on, with the effects mixed as desired, will continue to operate without further attention; the timing and sequence of the effects being controlled by motor-driven switches.

Generation of Effects

No attempt will be made to describe the operation and electrical circuit of each effect panel in complete detail as these have been designed to fulfil an exact requirement, and such a description would become lengthy and tedious. Instead a general picture will be given by the following list of the actual sounds obtained and the principles used to achieve these results.

Aperiodic Generator

Since it performs several important functions in the basic generation of the various noises, the function of this panel will be dealt with first. It is not in itself an effects generator but rather an auxiliary supply to the effects panels proper, and the unit is so named because its output consists of an irregular waveform including components of all frequencies within the audio range; but it possesses no truly periodic component.

This waveform is produced by amplifying the random noise voltages appearing across a small neon tube carrying a current of about 50 microamperes.

The neon tube and first stages of amplification tend towards microphonic coupling with the loudspeakers since the R.C. couplings are arranged to handle low frequencies; but this tendency has been overcome by mounting these items on a sub-chassis loosely suspended by four springs stretched outwards from the corners of the sub-chassis, the whole being electrostatically screened by a metal box with detachable rear cover. (Fig. 1.)

Excessive movement of this sub-chassis, despite the very flexible mounting, is prevented by hoops passing through clearance holes, so that valve replacements and jarring in transport cannot damage the light connecting pigtails.

Since the output from this generator is fed to a number of other panels, it is first taken through a cathode follower stage to eliminate unwanted coupling effects. The effective low impedance source of aperiodic noise takes care of this.

The front panel of this unit carries a meter which is connected through a diode to form a peak voltmeter. It is used in initial setting up to check the average output level of this generator, and it is interesting to observe when in operation that the pointer of this meter is moving continuously in a completely random manner, taking some seconds before repeating a particularly large swing in one or the other direction.

Distant Shell Burst

This effect consists of a series of dull explosions with rumbling echoes sounding at odd intervals and varying from one another in volume. The method of obtaining this result will be described in some detail as it is comparatively straightforward and typical of the manner in which the equipment has been developed.

Fig. 2 shows this circuit in simplified form, and as will be seen the output from the aperiodic generator, filtered by R_2, C_1 to remove the higher frequencies, is fed via C_2 to the grid of V_1, which valve is normally biased

* Mervyn Sound and Vision Co., Ltd.

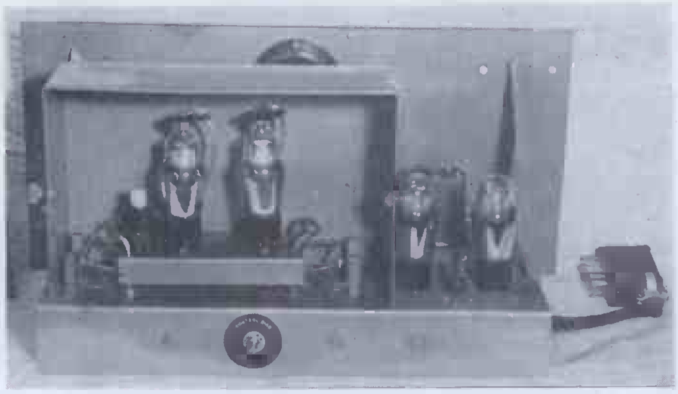


Fig. 1. Interior of aperiodic generator showing anti-microphonic mounting of sub-chassis.

beyond cut-off through R_4, R_5, so that no signal appears at its anode.

A rotating cam wheel having oddly spaced and shaped teeth operates a changeover switch so that in one direction C_3 is charged via R_1 to a positive potential, and in the opposite direction C_3 is connected through R_3 across C_4. This results in the grid of V_1 swinging fairly rapidly in a positive direction, since R_3 is small, and then more slowly returning to cut-off as R_5 is comparatively large, thus producing an envelope shape at the grid of V_1 with a steep front and a slow exponential recovery with the envelope containing the aperiodic noise. In other words, R_3 governs the "attack" of the sound while R_5 controls the "decay."

C_3 is small compared with C_4 so that the decay is the same even if C_3 is disconnected from C_4 by the switch during the decay period. R_1, C_3, is a long time constant so that C_3 does not have time to charge fully to the H.T. potential, but varies according to the shape of the cam teeth, hence the volume of the individual shell bursts varies also. C_2 and R_4 are proportioned so that R_4 presents a relatively high impedance to the aperiodic noise frequencies, while C_2 presents a similar high impedance to the envelope shape of the effects.

R_5 is made adjustable and brought out to the front panel for convenient adjustment of the length of echo.

Local Shell Burst with Whine

This differs from the previous effect in that the explosion is far louder and is preceded by a whistling noise, starting at a very high frequency and becoming lower in pitch and louder until it stops abruptly and is instantly followed by the shell burst.

The effect is controlled to give a salvo of about six bursts within a period of 30 seconds. The action is repeated at two-minute intervals.

The shell whine is produced by a triode connected as a blocking oscillator whose blocking frequency can be varied from the supersonic region to several hundreds of cycles per second by changing the applied grid bias. When this oscillator stops, the cathode current in the valve drops to zero suddenly and this is used to provide a pulse, applied through a cathode follower, which discharges a negatively charged condenser in the grid of the output valve.

This produces the noise of an explosion in a similar manner to the previously described effect.

Knobs are mounted on the front panel of this effect to adjust the relative volume of the whine and the length of echo of the explosion.

Local Machine Gun

This effect sounds as a series of short bursts taking place at odd intervals. Two triode valves are connected to form a multivibrator with a common cathode resistance and unequal time constants in the grid couplings. This arrangement produces across the cathode resistance a large positive pulse followed by a smaller positive pulse, and this waveform is applied to the grid of another triode normally biased to cut-off. A small amplitude of aperiodic noise is also fed on to the grid of the control valve, and the envelope shape produced at its anode when the multivibrator is running contains components of high audio-frequency.

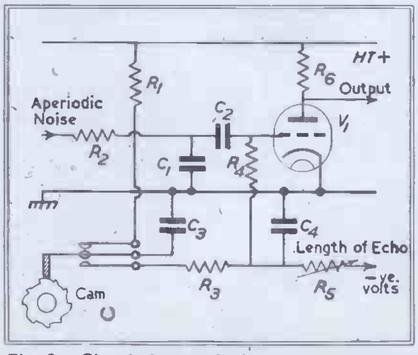


Fig. 2. Circuit for producing noise of distant shell burst.

The double pulse gives the characteristic "tutta-tutta" while the aperiodic components produce a more staccato "bark."

In controlling this effect care has been taken that the multivibrator remains quiescent, when not firing, always in the same direction, so that when the effect is initiated it starts off first with the large pulse followed by the smaller pulse.

The number of "rounds per second" is adjustable from the front panel by means of a control to vary the time constants of the multivibrator.

Distant Machine Gun

Except for a plain envelope shape without aperiodic noise components, and lacking in high audio-frequencies, this is very similar to the previous effect.

Teleprinters

These sound as two separate machines. One in the background is "ticking" continuously while a louder one starts and stops at irregular intervals controlled from the initiation switches.

Each teleprinter sounds as a series of "clicks" recurring at a preset average frequency, although the interval between any two adjacent "clicks" is not fixed.

This result is obtained by using a triode, connected with a transformer

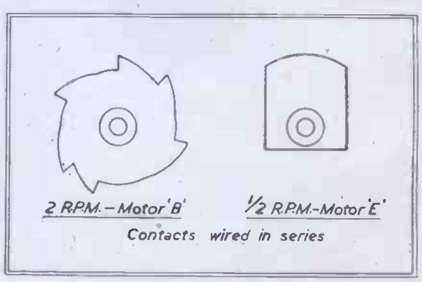
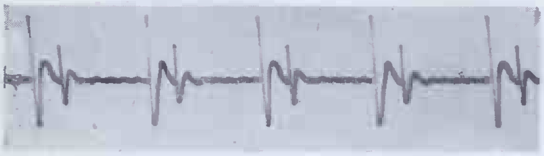


Fig. 3. Typical cams for varying timing of salvo of six shells. The segment cam produces a random "dud" at intervals, and has contacts wired in series with the main cam.

a



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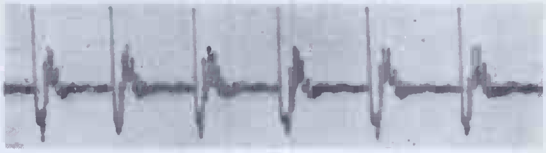


Fig. 4. Oscillograms of : (a) Sound of shell whine and burst, (b) Distant machine gun, and (c) Motor-cycle ticking over.

as a blocking oscillator, to produce the clicking effect. Each time the system recovers it oscillates at a high audio-frequency for several cycles then blocks again, which alone would give a fixed repetition rate governed by the time constants of the circuit. However, by taking the output from the aperiodic generator and clipping it through a diode, biased back so that only a few pulses or peaks get through per second, there is a means available for eliminating the regular repetition rate of the oscillator.

In practice these oddly spaced pulses are injected on to the grid of the oscillator through a small time constant, so causing the valve to trigger a little sooner than would be the case if it were running on its own, and since the triggering pulses are irregular the general pattern of the effect is also irregular except that it largely depends for its average repetition rate upon the recovery time of the oscillator so that there is no possibility of two "clicks" occurring one immediately after the other.

There is a separate oscillator for each teleprinter, and to prevent the triggering pulses from tripping both teleprinters in unison, one teleprinter is triggered by the positive peaks of the aperiodic noise, while the other is triggered by the negative peaks, which do no necessarily coincide with the positive peaks. Another valve is then needed to invert the negative peaks.

A front panel control is provided to adjust the average repetition rate of this effect.

Tank Effect

This effect gives the sound of a tank approaching, passing, and fading away into the distance. The exhaust note and track clatter are heard and the engine speed is varying constantly.

The noise of the engine is produced by applying a saw-tooth waveform with a steep front to a valve biased back almost to cut-off, while modulating the grid of this valve with the output from a separate oscillator running at a fixed frequency to represent the "ring" of an exhaust note which is due to an organ-pipe effect.

The saw-tooth waveform is generated by using positive pulses from a blocking oscillator to charge a condenser through a diode rectifier. The condenser then discharges more slowly through a resistance. Using this method the engine speed can be conveniently varied by altering the bias applied to the blocking oscillator, this being done by a motor-driven contact and a long time constant.

The track clatter is simulated by filtering certain bands of frequencies from the aperiodic generator output and adding these to the exhaust note, while the slow fade-in and fade-out of the effect is controlled by another valve with a long time constant in its grid-bias circuit also operated by a motor-driven contact.

Front panel controls are brought out for setting the average engine speed and the relative volume of the track noise as for travelling over hard or soft ground.

Aeroplane Effect

When this effect is initiated the sound of an aeroplane flying low is heard approaching, passing overhead with the attendant "Doppler" effect or apparent change in engine speed, then dying away into the distance.

The fundamental engine note is produced by an *LC* oscillator containing certain harmonics which is running the whole time and fed through two control valves in cascade. The first control valve is normally biased to cut-off so that nothing is heard, then when the effect is initiated by the appropriate motor-driven contact the negative bias on the valve is reduced, the valve commences to conduct and the sound fades-in. When the volume reaches a maximum the same valve draws grid current which loads the oscillator, thus reducing the frequency slightly and producing the "Doppler" effect. From this point the initiating voltage, still going slowly more positive, carries the cathode of the second control valve up above earth potential, causing that valve to conduct less until the sound fades-out completely.

Controls are provided on this panel to vary the duration time of the effect and the average engine speed.

Motor-Cycle Effect

This is intended to give the impression of a motor-cyclist starting up, riding off and changing gears; then fading-out into the distance. Also riding up, slowing down and stopping.

The engine note is obtained in a similar manner to that of the tank effect except that the "ring" of the exhaust is more pronounced in this instance. The impression of changing gears is produced by relays which are set to operate when certain points are reached by the slowly rising control voltage which has already started the engine and raised its speed. These relays switch into the grid circuit of the blocking oscillator suitably charged condensers so that momentarily the oscillator is stopped and no exhaust note produced, then when it recovers it rises in frequency again, but more slowly this time, to imitate an engine accelerating in a higher gear. Fading-in and fading-out are done by another control valve, and controls for adjusting the maximum

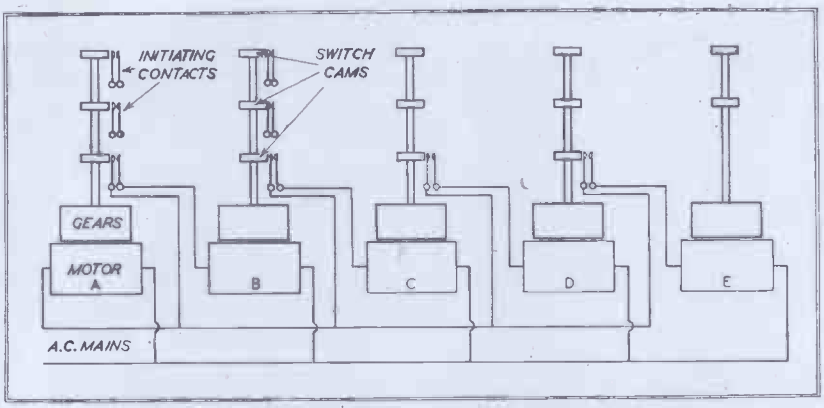


Fig. 6. Diagrammatic wiring of motors and cams in initiation control panel, showing method of preventing motors from keeping in step.

engine "revs" and exhaust note are accessible from the front panel.

Before leaving the actual effects generators it might be as well to point out that this part of the equipment is running under very favourable conditions. Apart from several diodes and two pentodes on the aperiodic generator, triodes are used throughout, and the high tension current for these averages just under one milliampere per valve.

Component values are not critical and 20 per cent. resistors and condensers are used everywhere. Preset controls are used for initial setting up and these do not appear to require further attention even after valve replacement.

Initiation Control

As will be seen from the photograph of this unit, it carries five small synchronous motors geared down to drive the switch operating cams at speeds ranging from one revolution in 30 seconds to one revolution in 18 minutes. Four of these motors carry an extra cam apiece which at each revolution of the camshaft interrupts the mains supply to the adjacent motor for several seconds, so that one motor runs continuously while the others are stopped at intervals by the previous motor in the chain as shown in Fig. 6.

This means that if a number of effects are set up to operate at the same time, the pattern will not repeat itself for a very long period. Contacts are also chosen so that individual effects do not repeat the same sounds. A typical instance is that of the local shell burst where one motor drives a switch to select a 30 seconds period at two-minute intervals approximately, while another motor drives an irregularly shaped cam to initiate the actual shell bursts during that period, and since these two motors do not keep in step with one another a different pattern is formed for each salvo. (Fig. 3.)

It should be realised that this motor-driven unit is only required in this instance to allow the equipment to function automatically, and that a series of manually operated switches or push-buttons could equally well be used to initiate the effects as wanted. Such a scheme would be more suitable for studio work or the presentation of stage plays.

Mixing Amplifier

The outputs from the eight effects already described can be separately controlled at the mixer panel, the output from which is then passed through a voltage and driver amplifier to feed the four power amplifiers.

There is also incorporated an automatic limiter stage which enables any one effect to develop the full power output from the equipment, while if two or more such effects happen to occur together the overall gain of the amplifier is reduced to prevent overloading. Another feature is the provision of a thermal delay switch in the heater supply to the driver valves which is necessary to prevent any signal from reaching the loudspeakers until such time as the various effects have settled down to normal working voltages, which process takes about a minute.

Power Amplifiers

These follow conventional practice, each consisting of a pair of tetrodes operating in Class AB and supplied from a built-in power pack mounted on each chassis. Speaker outlets are arranged to match into 500-ohm lines, making long speaker runs possible without appreciable attenuation or loss of quality, while dummy loads are automatically switched in to preserve matching when speaker jacks are withdrawn. Extension speakers supplied with the equipment are fitted with controls for individual volume setting.

Conclusion

Although, as will be seen from the foregoing description, this apparatus has been designed to cover a specific requirement, the method of sound generation used is very flexible and the effects mentioned are only representative of what can be achieved by this means.

The possible range of effects is, of course, limited by practical considerations such as complexities of circuit and number of valves used, so that complex sounds like human speech are unlikely to use this system in preference to recorded sounds.

However, where it is practical to produce a sound effect electronically the following advantages are apparent:

Ready means of modifying the effect as required, ability to synchronise with other events, and freedom from wear and tear over long periods.

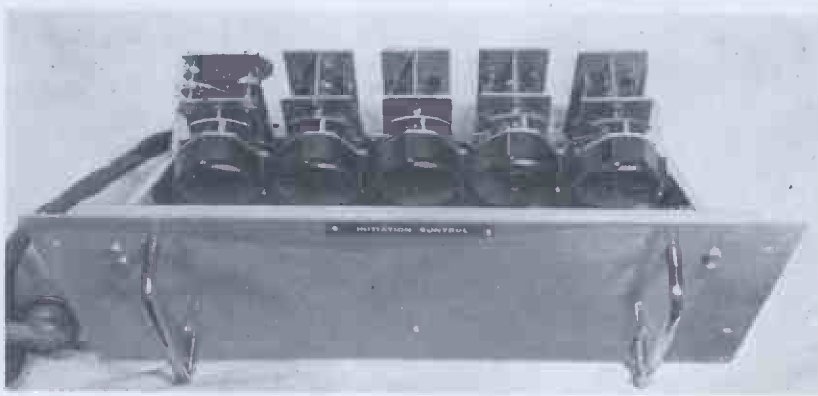
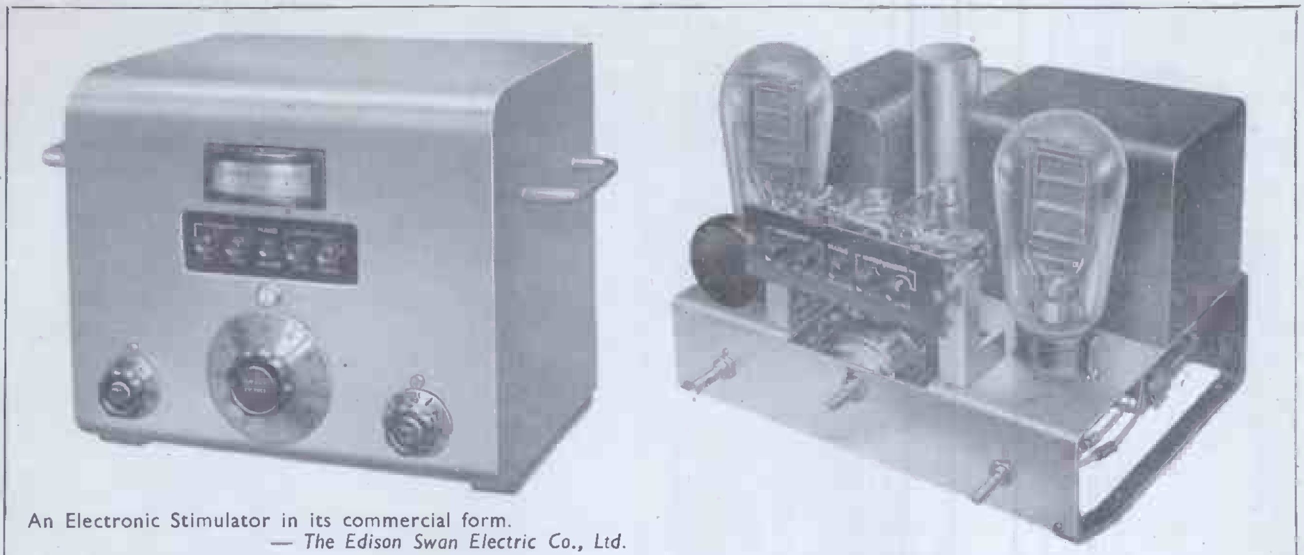


Fig. 5. Initiation control panel, showing small motors.



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Electronic Stimulators

For Medical and Physiological Purposes

By W. GREY WALTER, M.A.,* and A. E. RITCHIE, M.A., M.B., Ch.B.†

ELECTRICAL stimulation of the human body is as old as the history of electricity itself. Until the last few years the methods used for such stimulation have kept pace with the development of physical science (Galvanism, Faradism, Condenser discharges, Thyratrons). At the present time most of the apparatus in routine use is twenty years out of date. Moreover, anyone wishing to use modern methods for their accuracy or convenience has had to design and build for himself an apparatus which any electrical instrument maker could construct quickly and cheaply if he were given the specification and design.

Early Methods

The theoretical basis of stimulation studies is the conception of excitability as a function of time. The earliest observers found that damaged nerves and muscles responded less readily to shocks from an induction coil (" Faradic stimulus ") than to a direct current (" Galvanic current "). This is crystallised in the classical test for nerve lesions which make the injured muscle unresponsive to a " Faradic " shock, but leave it responsive to a " Galvanic " one. The explanation for this has been investigated very thoroughly by Lapicque (1926), Keith Lucas (1917), Adrian (1917), Bourguignon (1923). The detailed interpretation of some observations is still controversial, but there is complete agreement that if stimuli of varying strengths and durations are applied to a muscle or nerve so as to evoke in each case a response (contraction or sensation) of the same magnitude, the relationship between strength and duration of the stimuli can be represented by a curve of the form shown in Fig. 1a. From this curve—which by a change of coordinates could represent any excitable tissue—it is clear that: (i) Below a certain strength of stimulus, termed the " rheobase," no response occurs. (ii) If the stimulus lasts an indefinitely long time it can be quite weak. (iii) Beyond a certain length of stimulus there is no increase in efficacy. (iv) As the stimulus is shortened, it must be increased in strength to remain effective. (v) When the stimulus is extremely short it must be extremely large. When the excitable tissue is damaged the form of the curve is found to be different, as in Fig. 1b. The most striking change is not in the rheobase value but in the efficacy of short stimuli, which for a given duration must be larger than in the normal case. The Galvanic-Faradic test is simply the fixing of two points on this curve; the Galvanic current is a pulse of indefinitely long duration, with which the rheobase may be measured, and the Faradic shock has the time relations of an induced current, that is, it is a brief transient with some damped oscillations, the precise duration depending upon the characteristics of the coils and core. Usually, the Faradic stimulus may be considered as a roughly exponential pulse with a physiologically effective duration of about one millisecond. The induction coil is clearly most unsuitable for exact measurements since, in the first place, the duration of the pulse is not independent of its magnitude and, secondly, the strength of the stimulus for a given setting of the controls will vary with the load, that is the resistance of the patient, owing to the poor regulation of the secondary coil.

Graded condenser discharges were

* Burden Neurological Institute, Bristol.
† Dept. of Physiology, University of Edinburgh.

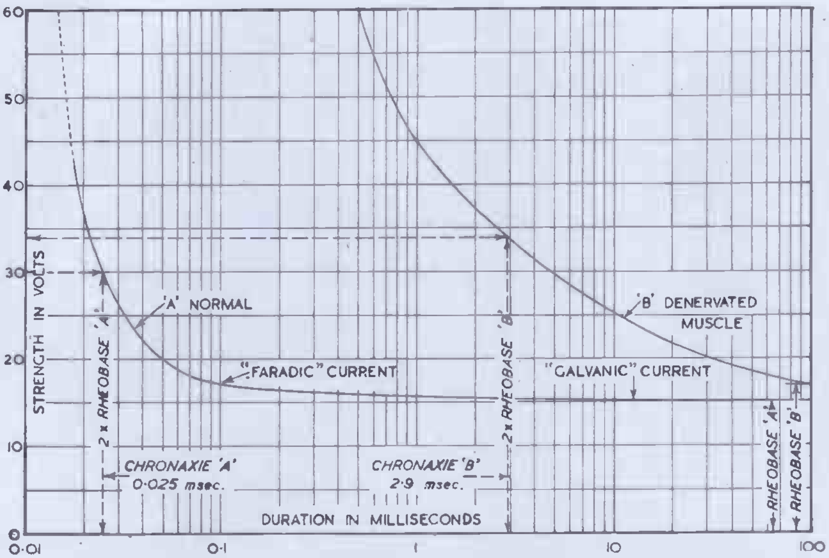

Fig. 1. Ideal Strength—Duration curves showing construction for obtaining the Chronaxie value. A. Normal, B. Denervated Muscle.

favoured by the French school, but here again it is difficult to ensure that the strength and duration are independent of one another and of the patient's resistance. The Cambridge workers generally used a calibrated contact-breaker in a low resistance or "constant voltage" circuit. This method is accurate, but inconvenient for clinical application.

Electronic Methods

The design of electronic stimulators has in the main followed the development of time-base potential generator circuits, wherein pulses of controllable frequency are produced; in the time-base application of such circuits the repetitive potential change is applied to a high impedance load consisting of the cathode-ray tube deflector plates, whereas for biological application the pulses caused by the discharge of the condenser through the low impedance of the trigger mechanism are made use of.

Daly (1924) and Cullen (1941) have described neon-tube relaxation oscillators for nerve stimulation, but their output voltage is too low to be of general use.

The "squegging oscillator" of Appleton, Watson Watt and Herd (1926) was adapted by Campbell (1929) as an alternative to the induction coil, and is a very simple and reliable device, which can be satisfactorily operated from a raw A.C. supply. With the introduction of the gas-filled triode a large number of time-base circuits rapidly developed, and many of these have been adapted for excitation of living tissues.

Schmitt and Schmitt (1932) described the original basic form as a single valve relaxation oscillator; more elaborate designs incorporating such refinements as a pentode charging control, "magic-eye" indicator, and power output valve have been used by Fender (1939), Delaunois (1939), Connerty and Johnson (1942), and Thorpe and Robinson (1943). While these circuits afford reliable and controllable alternatives to the induction coil, it is important to realise that they have little biological superiority; as has been described, the most exact measurement of excitability is in terms of pulse duration and pulse intensity, and frequency variation as such is of little physiological significance. Moreover, with all the above circuits variation in frequency over wide limits is accompanied by variation in the duration of the pulse (which is of condenser discharge form), and the employment of a power output valve and output transformer tends to impair rather than improve the physiological value.

Hard-valve pulse generators can be adapted for biological stimulation in almost any of their standard time-base forms, subject to the limitations just mentioned; hard-valve generators specifically designed to deliver pulses variable in duration, intensity and frequency have been employed by Bauwens (1941), Denny (1944) and Ritchie (1944) as discussed below.

For particular biological problems, where exact assessment of excitability must give way to other requirements, a number of electronic designs have recently been used. Stimulation of deep-seated structures in the intact and conscious animal can be done by means of a buried coil and some form of "transmitter" operated at a distance; various methods or achieving such stimulation of internal structures have been used by Louchs (1933), Chaffee and Light (1934), Fender (1941), and Greig and Ritchie (1944). The production of electric stimuli in the form of spark discharges which could be applied to very minute areas of skin has been successfully used by Bishop (1943) in an investigation of the separate sensory organs in human skin.

Electronic stimulators may therefore be divided into two main categories:

1. Those designed mainly for qualitative work or therapy where exact measurements are not required (Thorpe and Robinson, 1943).
2. Those intended for measurements of excitability as described above.

There is no reason why instruments in Category 2 should not be useful also for therapy or qualitative observations, but the reverse does not apply.

Instruments in Category 2 have never been readily available because there has been no agreement as to the precise design to be adopted. The main virtue of modern apparatus is its accuracy, hence uniformity of range, scales, and calibration is essential if the full value of the new methods is to be obtained.

Essential Requirements

The essential feature of any quantitative stimulator is that it should generate pulses of which either the voltage or the current is constant within 20 per cent. at any output setting for a range of load resistance from 5,000 to 100,000 ohms. This means that the internal resistance of the stimulus output circuit should be either of the order of 1,000 ohms ("constant voltage" or c/v.) or of the order of ½ megohm ("constant current" or c/c.). The amplitude of the pulses should be adjustable from 0-10 volts c/v. (0-2 mA c/c.) on a "low" control, and 0-100 volts c/v. (0-20 mA c/c.) on a "high" control. The duration of the pulses should be adjustable in steps from 0.1 sec. to 0.02 msec. c/v., or 0.1 sec. to 0.1 msec. c/c. The repetition rate should also be adjustable from about 1 pulse per second to about 1,000 pulses per second. The pulse shape may be either rectangular or exponential but calculations are simpler in the former case. There should be a minimum of spurious transients in the pulse waveform. These considerations limit the possibilities somewhat, but there are many practical designs. At one extreme there is very great accuracy and flexibility combined with bulk and expense; at the other, adequate accuracy, restricted application, portability and cheapness. Most of the theoretically possible patterns have actually been made and used. All employ valves to generate pulses of electrical energy of suitable amplitude, duration and repetition rate. All can be made entirely mains-operated and safe for the operator and subject. Most of the technical experiments in this country have been made by Bauwens (1941), Denny (1944), and Ritchie (1944, 1945). The most promising circuits have recently been tested against one another and the results of these tests have cleared the subject of some uncertainties and established principles upon which an accepted design and procedure may be based.

Expression of Results

The reality and importance of the stimulus strength-duration (S/D) curve are accepted by all, but the best way of expressing results is still debated. Lapicque suggested that the most convenient measure of the time relations of excitability is the shortest effective stimulus of twice rheobasic strength. This he called the "chronaxie." The value of "chronaxie" is obtained simply by measuring the rheobase strength, doubling it, and reducing the duration until it is only just effective. The value may be obtained graphically from a S/D curve as shown in Fig. 1. The degree of confidence which may be placed in this measurement depends upon whether or not significant variations in S/D curves are such as to produce significant variations of chronaxie. On the whole they are, but it would appear more satisfactory to plot the whole curve from observations and to use the chronaxie value as a brief indication of the position and shape of the curve. Lasalle (1928) proposed another index which takes into account both the time relations of excitability and the rheobase value. This is (rheobase squared multiplied by chronaxie) and has the dimensions of energy; a more logical representation, perhaps, of empirical data.

Effect of Load

An important factor which seems to have been overlooked by many physiologists and most technicians is that living tissue presents a highly reactive load to the stimulator. Thus, Denny (1944) mentions "the patient circuit which may be considered as a purely resistive load." In fact, the simplest equivalent circuit which is found empirically to represent a living load of the type actually encountered is a resistance of, say, 10,000 ohms shunted by a capacitance of about 0.02 μF. The values of both elements vary in different individuals and the variations in vector impedance have been studied for their own interest by several workers (Vigouroux 1888, Gildermeister 1919, Brazier 1933, Horton and Van Ravensway 1935), but the capacitative reactance is always present to about the extent indicated. The effect of this reactance upon the waveform of an electrical stimulus is, of course, quite striking.

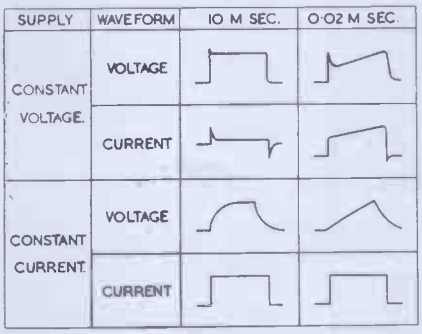

Fig. 2. Waveform of current and voltage in living load with Constant Voltage (c/v) and Constant Current (c/c) generators.

The effects are of more than academic interest, however. If the living excitable tissue presented a purely resistive or ohmic load to the output circuit, measurements made with a c/v. and c/c. circuit would be identical in the same circumstances. Since, in fact, a capacitative reactance is present, the current waveform will tend to the differential of the voltage waveform with a constant voltage output circuit, while the voltage waveform will tend to the integral of the current waveform with a constant current output circuit. This is illustrated diagrammatically in Fig. 2. It is seen that the current and voltage waveforms are similar in the case of the c/v. circuit only at short durations and in the case of the c/c. circuit only at long durations of pulse. The physiological effect of this is that in the c/v. case long pulses are "wasted" while in the c/c. case short pulses are apparently more effective. When this effect was measured it was predicted that the apparent chronaxie as measured with c/v. instruments should be about one-tenth that obtained with c/c. circuits. This has been confirmed. A rough average value for normal motor chronaxie measured with constant voltage pulses is 0.02 msec., while with constant currents it is about 0.2 msec. A further effect of the tissue reactance is that with a c/c. circuit the voltage can rise to high values if the tissue impedance is high. This occurs if the skin is too dry or unusually thick, and in these circumstances the c/c. stimulus may be quite painful. A characteristic of the c/v. stimulus is that it is relatively unobjectionable over the range of voltages used for nerve and muscle testing. These phenomena are of considerable theoretical interest but need not be considered further here.

A Practical Design

With these considerations in mind, and remembering also the limitations imposed by war conditions, an instrument has been designed to fulfil the following functions:

(*a*) Excitability measurements on exposed brain, nerve and muscle, either on the operating table or in the laboratory.

(*b*) Excitability measurements on nerve and muscles through the skin for diagnosis and prognosis in the clinic or for research.

(*c*) Qualitative stimulation (single shocks or "tetanic") for exploration or experiment or teaching.

(*d*) Therapeutic stimulation ("Faradism") of nerves and muscles.

(*e*) Therapeutic stimulation ("Galvanism") of nerves and muscles.

(*f*) Iontophoresis by direct current.

Widespread use of such an instrument is expected to:

(*a*) Improve the accuracy of diagnosis and prognosis in cases of peripheral nerve injury and disease.

(*b*) Decrease the discomfort to the patient during such examinations.

(*c*) Make possible investigations and tests beyond the range of equipment at present in use (*e.g.*, excitability measurements on the exposed cerebral cortex, for which independent control of amplitude duration and repetition rate are essential).

(*d*) Standardise the scales and units used for excitability measurement, enabling the various centres to compare results and to follow the progress of patients after transfer from one centre to another.

(*e*) Elucidate the various effects and anomalies familiar to clinicians, physiologists and physiotherapists, but unintelligible as yet because of the variations and fundamental inaccuracies of present methods.

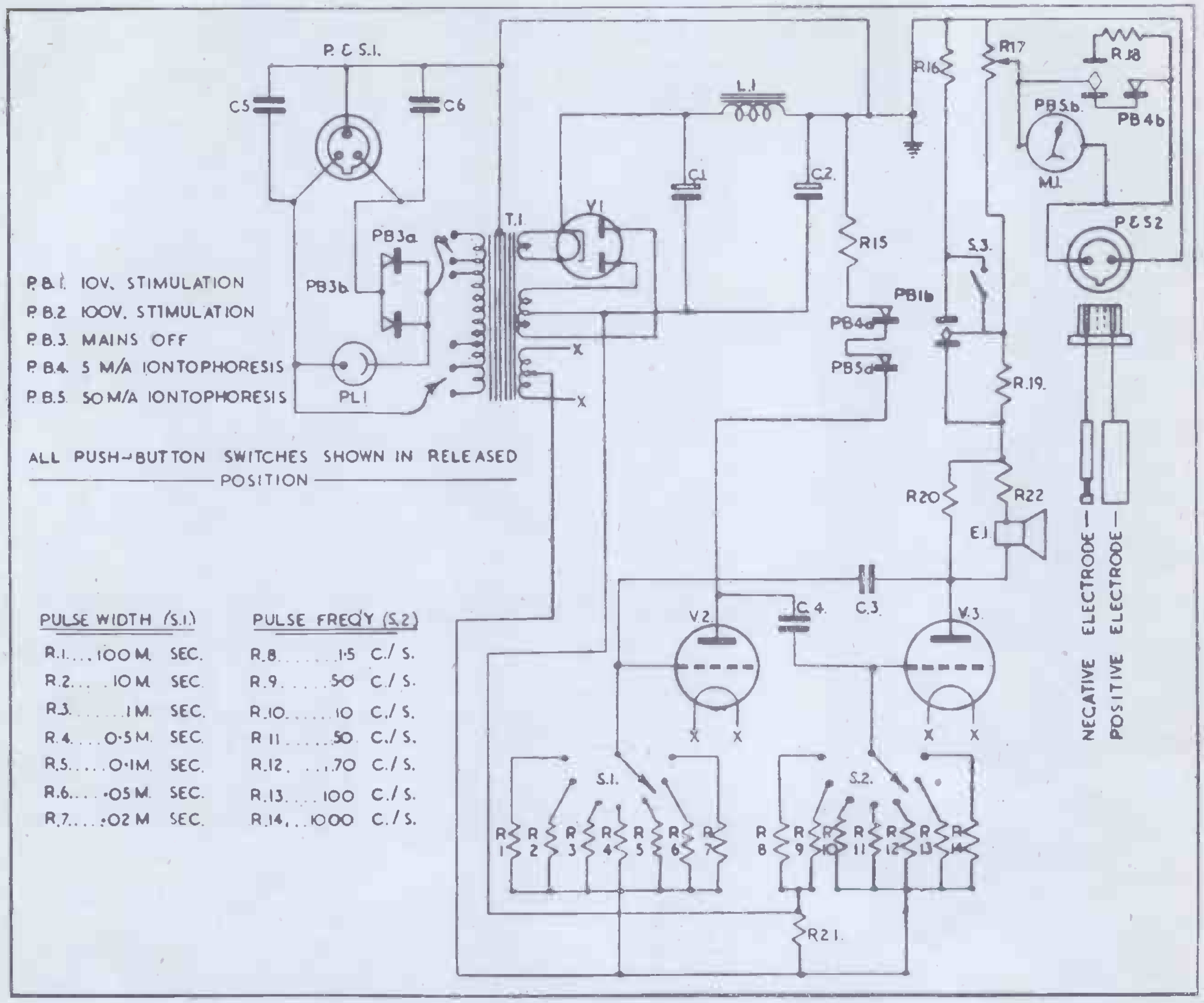

Fig. 3. Circuit of Ritchie—B.N.I. square wave stimulator.

Component Values

C_1 8.0 μF.	R_1 10MΩ	R_7 1KΩ	R_{13} 3.3MΩ	R_{19} 1,350Ω NI	V1 Mazda UU.5
C_2 8.0 μF.	R_2 1MΩ	R_8 120MΩ	R_{14} 330KΩ	R_{20} 1,880Ω NI	V2 Mazda PP.5/400
C_3 0.01 μF.	R_3 100KΩ	R_9 35MΩ	R_{15} 3,000Ω NI	R_{21} 400Ω NI	V3 Mazda PP.5/400
C_4 0.002 μF.	R_4 47KΩ	R_{10} 35MΩ	R_{16} 166.6Ω NI	R_{22} 3,300Ω RMA.8	PL1 250 V Neon
C_5 0.0015 μF.	R_5 10KΩ	R_{11} 7MΩ	R_{17} 1.500Ω Pot'r.		M1 0-5 mA Meter
C_6 0.0015 μF.	R_6 4.7KΩ	R_{12} 4.7MΩ	R_{18} 50 mA Shunt		L_1 Choke 20 H. at 70 mA
					T1 Mains Transformer
					E1 High Impedance Diaphragm Type Earphone

Push-button switches : "*a*" suffix, indicates upper wafer ; "*b*" suffix, indicates bottom wafer

This apparatus can replace and supersede the following equipment :

(*a*) Induction coils and interruptors used for "Faradism."

(*b*) Batteries and eliminator units used for "Galvanism."

(*c*) Batteries and eliminators used for iontophoresis.

(*d*) "Chronaximeters," using condenser discharges or contact breakers.

(*e*) Stimulators for neuro-surgery such as those using thyratrons or contact breakers.

The instrument is basically the same as that described by Ritchie (1944), and is a power multivibrator. The only alterations are : (i) The provision of a single small condenser in the frequency control circuit with variation by means of selected resistors together with alteration in the bias resistor (Fig. 3). (ii) Provision is also made for direct current by switching off one valve altogether. (iii) For direct stimulation of brain and other exposed tissues a low-voltage setting is provided. In its commercial form it is manufactured by the Edison-Swan Electric Co., Ltd., to the authors' specification.

(*Continued on p. 608.*)

Space Charge and Electron Deflections in Beam Tetrode Theory

Part 2

By S. RODDA, B.Sc., F.Inst.P.*

6. Formation of a Virtual Cathode

IN order to explain what happens when a larger current is projected through the screen than can be transported to the anode it has to be supposed that a part of the current is reflected back to the screen. If the electrons are projected normally through the screen they could reverse their trajectories in the screen-to-anode space at a plane where the potential falls to zero, *i.e.*, if a "virtual cathode" were formed. At a virtual cathode a sorting action takes place, owing to the initial spread in velocities associated with thermionic emission, so that the fast electrons are transmitted to the anode and the slow electrons are reflected back to the screen. In the virtual cathode-to-screen space the returning electrons will add to the space charge density due to the forward electrons.

Let the virtual cathode plane be distant x_1 from the screen and x_2 from the anode; suppose that J_T = total current density projected through the screen and that J_A = current density reaching the anode. At the virtual cathode position dV/dx = zero and V = zero, as for a real cathode. (*See* Fig. 8.)

$$\text{Hence } x_1 = \sqrt{\frac{\left(\frac{2e}{m}\right)^{\frac{1}{2}}}{9\pi}\frac{V_1^{3/4}}{\sqrt{2J_T - J_A}}} \qquad (1)$$

as for a diode with space charge density due to the sum of J_T forward and $(J_T - J_A)$ back.

$$x_2 = \sqrt{\frac{\left(\frac{2e}{m}\right)^{\frac{1}{2}}}{9\pi}\frac{V_2^{3/4}}{\sqrt{J_A}}}$$

So that on summing:

$$x_1 + x_2 = x_a$$

$$= \sqrt{\frac{\left(\frac{2e}{m}\right)^{\frac{1}{2}}}{9\pi}\left[\frac{V_1^{3/4}}{\sqrt{2J_T - J_A}} + \frac{V_2^{3/4}}{\sqrt{J_A}}\right]} \qquad (2)$$

If this equation is rewritten in terms of "diode units" we get:

$$V_2^{3/4} = \sqrt{J_A} - \frac{\sqrt{J_A}}{\sqrt{2J_T - J_A}} \quad \ldots\ldots (3)$$

If J_T is made infinitely large a rational solution is now given, $x_1 \to 0$, so that the virtual cathode is formed close to the screen and the limiting anode current is that of a diode of gap x_a and anode voltage V_2.

It is clear that in general V_2 and J_A will increase together from small values, but an examination of the Equation (3) shows that when $J_A = 2J_T - (2J_T)^{2/3}$ the slope of the J_A, V_2 curve is infinitely steep, and that for higher values of J_A the slope is negative, so that the J_A, V_2 curve begins to bend back. The corresponding value of V_2, denoted by V_σ at which the curve becomes infinitely steep is given by the relation:

$$W_\sigma = [(2J_T)^{1/3} - 1]^2 \quad \ldots\ldots (4)$$

where $W_\sigma = \dfrac{V_\sigma}{V_1}$

It is supposed that the negative resistance region is unstable, and that it can be a cause of oscillations in a positive grid triode.[23] We may assume that when $V_2 = V_\sigma$ the anode current jumps to its full value J_T and that V is therefore the "knee voltage" corresponding to V_2. This should be compared with the value:

$$W_K = [J_T^{1/3} - 1]^2$$

assigned to the "knee voltage" on Gill's theory.

The results of the two theories are shown by the curves of Fig. 9, in which J_A is plotted against the ratio V_2/V_1.

Suppose, for example, we start with J_T = 2.5 units and a high value of anode voltage. As the anode voltage is reduced the anode current will be unaltered until the boundary curve aa is reached. The total current can no longer be fully transported, so that the system should jump to the virtual cathode mode and should remain in this until the anode voltage is raised above V_σ. The behaviour of the system is thus apparently characterised by an enormous hysteresis loop.

Unfortunately for the truth of the virtual cathode theory the quantitative agreement between the actual knee voltages and the calculated knee voltages is very poor—the calculated values are much too high.[24] For J_T = 2.5, W_σ is experimentally approximately 0.2 instead of 0.5 and therefore is nearer the limiting value set by the curve aa. As a consequence the hysteresis loops are not nearly so large as the synthesis of the virtual cathode theory and the Gill theory would indicate, although small loops can sometimes be demonstrated by taking dynamic characteristics on a cathode ray oscillo-

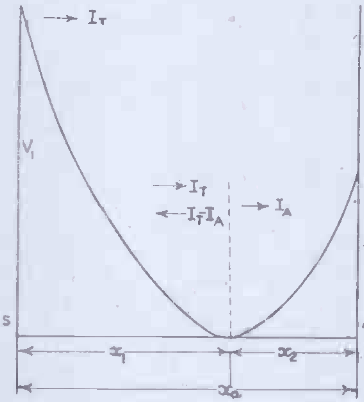

Fig. 8. Potential distribution when a virtual cathode is formed.

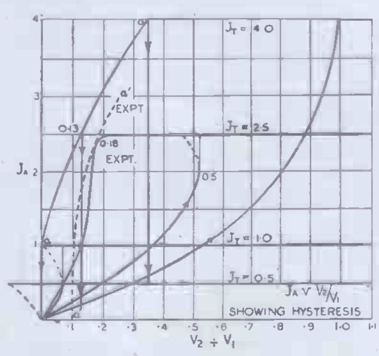

Fig. 9. J_A plotted against V_2/V_1.

graph, especially when the A-S gap is large.

Another difficulty is presented by both theories since they indicate that if I_T is low the value of W_k is zero. In practice, W_k follows the curve a'a' instead of aa, and is roughly 0.1 even at low projected current densities. It will be shown that these difficulties can be overcome if it is assumed that the electrons are not all projected normally through the screen but that they enter the screen-to-anode space over a range of angles to the normal.

A similar conclusion has already been drawn by Strutt and Van der Ziel in an important paper entitled "Uber der Elektronen raumladung zwischen ebenen Elektroden, unter berucksichtigung der Anfangsgeschwindigkeit und Geschwindigkeitsverteilung der Elektronen," published in *Physica*, 1939,[25] if it is borne in mind that the velocity distribution of electrons projected into the S-A space arises from deflections at the grid and screen wires.

It would be an error to suppose that such a velocity distribution arises from the drop in potential between screen wire turns, except in so far as deflections are produced in the local fields around the wires. The field beyond the screen rapidly becomes uniform (unless the distance between adjacent turns is large) so that all electrons crossing a given plane will have the same total velocity, and they will therefore have the same forward velocities unless they have been deflected.

7.1. Electron Deflections

The rôle played by electron deflections in a positive grid triode, although referred to by Tonks, was first worked out by Below[26] who showed that the initial rising part of the I_A, V_2 characteristic could be ascribed to the effect of electron deflections at the grid. Consider a plane triode with grid at a positive potential V_1, and suppose that an electron enters the grid-to-anode space inclined at an angle θ_1 to the forward direction. If no further transverse forces act on the electron during its flight it will retain a constant transverse velocity. Hence if θ is the inclination of the electron trajectory at the plane where the potential is V, $V_1\sin^2\theta$ = constant = $V_1\sin^2\theta_1$. At the position where the voltage V is $V_1\sin^2\theta_1$, θ will equal 90°, so that the electron will be brought to rest in the forward direction, and will begin to reverse its trajectory. The condition

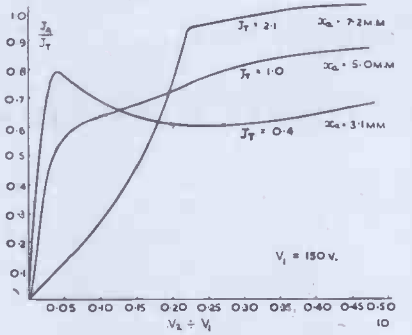

Fig. 10. Effect on characteristics of increasing relative space charge density, by increasing x_a.

in the plane case that an electron shall reach the anode is that there should be no potential between screen and anode lower than:

$$V_1\sin^2\theta_1$$

In a tetrode the same considerations apply if by V_1, θ_1 are understood the potential of the screen and the angle of entry of the electron into the S-A space.

θ_1 will, however, arise as the result of deflections by the control grid wires and by the screen grid wires. If, now, one could measure the primary current incident on the anode as a function of the potential minimum voltage V_m, the current collected will be due to those electrons whose deflections range from zero to $\sin^{-1}\sqrt{V_m/V_1}$; the more widely deflected electrons will be reflected back to the screen.

An immediate consequence of such a distribution-in-angle of the electrons projected into the S-A space is that the virtual cathode condition cannot be attained, since with a zero potential minimum all the electrons must surely be reflected. It is therefore necessary to modify the virtual cathode theory by postulating that V_m must be of sufficient height to transmit, at a given value of V_2, the observed anode current. Precisely the same mechanism is arrived at if it is considered that the initial rising part of the I_A/V_2 characteristic is a

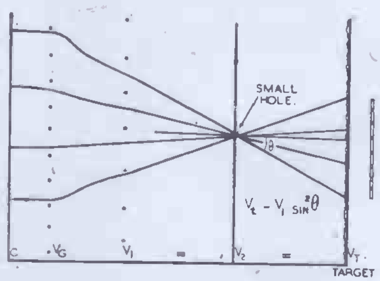

Fig. 11. Method of demonstrating deflections.

consequence of Below's theory[27] which must be modified by replacing the anode potential, V_2, by the potential minimum V_m produced by space charge. An experimental result which illustrates the effect of space charge is shown in Fig. 10, where a fixed current is projected into the S-A space. Since the screen and control grid voltages are kept constant the deflections of the electrons will be constant, except in so far as the deflections vary slightly with the electrostatic intensity on the anode side of the screen. If the S-A gap is made large the knee voltage greatly increases, but not to the value predicted by the virtual cathode theory (W_σ = 0.36 when I_T = 2.1).

In order to demonstrate the magnitude of electron deflections in actual valves the author has employed the simple method shown in Fig. 11.[28]

The anode of the tetrode has a small hole drilled in it. Electrons which emerge from the hole impinge on a fluorescent target. If the anode and the target are maintained at the same potential the electrons will travel in straight lines from the hole to the target. The results when current flows are indeed spectacular in that a long thin line appears on the target, showing that some electrons are greatly deflected in the plane normal to the grid and screen turns. (The fact that the line remains thin demonstrates that the effect cannot be due to space charge repulsion in the beam of the anode-to-target gap.) It is not essential that the anode should be kept at the target potential. If the potentials are unequal, the trajectories in the anode-target space will be parabolic.

It is a disadvantage with unequal screen, anode and target voltages that the hole will behave as an electrostatic lens. With a very small hole this is not serious except at low anode voltages.

Experiments show that the maximum angular deflection varies greatly with control grid voltage, as the following table shows:

V_1 = 135 volts		
Vg	$\sin^2\theta_1$	$V_1\sin\theta_1$
− 7.5	0.06	8.1
− 5.0	0.10	13.5
− 2.5	0.15	20.2
0.0	0.17	23.0
+15	0.06	8.1

Near cut-off the deflections are small; with bias approaching zero they rise to a maximum and then with increasing positive bias the deflections decrease again. This behaviour is what one would expect on electron optical considerations.

7.2. Deflection at the Control Grid

The simplest approach to the problem of calculating the deflections at the control grid is to suppose that the apertures between adjacent grid turns form cylindrical electron lenses. If the potential distribution is known, taking into account the presence of space charge, the precise trajectories can be determined step by step using Gabor's formula for the curvature

$$\frac{1}{R} = \frac{\partial V/\partial n}{2V}\cos(\Psi - \theta)$$

The potential gradient $\partial V/\partial n$, makes an angle Ψ with the axis, and the normal to the electron trajectory an angle θ at a point where the potential is V. The co-ordinate system is taken with its axis a straight line normal to the grid plane passing midway between adjacent turns; the Y axis may be taken normal to this, in the grid plane.

When the control grid turns bear no charges the electrons are uninfluenced by the presence of the grid. The grid must then be at the (positive) potential V_f which would be found at the grid plane in the absence of the grid. When the control grid is at a negative potential the lens is convergent and the electrons are strongly deflected inwards towards the axis, but the beam cannot occupy the whole width between adjacent turns, since the electrons cannot come nearer a grid wire than to a zero equipotential. It seems reasonable to suppose that in this case the electron which has the maximum transverse velocity imparted to it is one which has been turned inwards from the zero equipotential and crosses the axis almost at right angles near the grid plane, where the potential is $\overline{V}$. Actually such an electron would swing across from one grid wire to the neighbourhood of the adjacent wire and be repelled inwards again, so that its transverse velocity is less than that acquired by falling through a potential difference $\overline{V}$. When the control grid is positive, the outer electrons are turned inwards from positive equipotentials. The maximum lateral velocity will therefore not exceed its value at zero grid bias, and for $V_g = V_f$ it will diminish to zero. Again, for bias values which are negative the transverse velocities must diminish, since $\overline{V}$ decreases. Finally, just at the point of cut-off when the emitting width is zero, the beam width through the lens is so small that the extreme deflection becomes very small indeed.

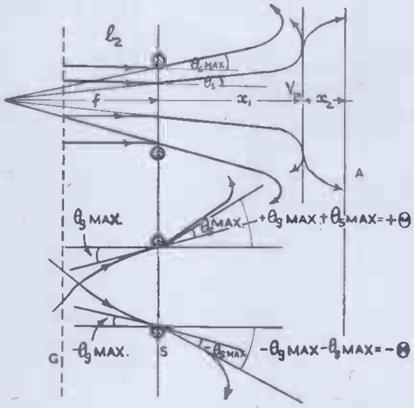

Fig. 12. Electron trajectories in neighbourhood of screen wires, showing divergent lens effect.

It is interesting that instead of finding the trajectories in the actual system one can use a conformal transformation to a new geometrical system. The potential should at corresponding points be equal to that of the old system divided by the square of the modulus of transformation at the point considered. The new trajectories are the conformal transforms of the trajectories in the first system (Gabor[29]). The most convenient and practical method of examining the trajectories is to use the rubber drum model, which is illustrated, for example, in the paper by Jonker already referred to.

7.3. Deflection at the Screen

After an electron has escaped from the locally disturbed field near the grid plane its angle of inclination to the forward direction will decrease in such a way that $V\sin^2\theta$ remains constant. The value of θ when $V = V_1$ will be referred to as the reduced value of θ. At the screen there will be an additional angular deflection. (Fig. 12.)

Suppose that just before reaching the screen plane, the reduced angle of inclination is θ_g, due to deflection at the grid, and that the electron is given a further angular deflection θ_s near the screen wires. The total inclination after emergence from the screen plane will be $(\theta_g + \theta_s)$, so that the transverse velocity in electron volts:

$$V_t = V_1\sin^2(\theta_g + \theta_s) \approx V_1(\theta_g + \theta_s)^2 \quad (1)$$

if the angles are small. Thus if $\theta_s = \theta_g$ the overall value of V_t is four times the value attained at the control grid alone. At the screen Calbick's formula[30,31] for focal length f can be used, since the aberrations are small. An electron traversing the screen plane at a distance y from the axis of a lens will experience an angular deflection y/f radians. If we assume that the charge induced on the screen wires is mainly due to the electrostatic intensity in the control grid to screen space, then $f \approx 2l_2$ where l_2 is the grid-to-screen gap. Hence the value of θ_s is $y/2l_2$.

Let N_s = t.p.cm. of the screen winding; the maximum value of y, corresponding to an electron trajectory passing close to a screen wire, is $1/2N_s$, so that the maximum angular deflection is $1/4N_sl_2$ radians. As an example, let N_s = 10 t.p.cm., l_2 = 0.1 cm.:

$$\theta_{s\cdot max} = \frac{1}{4} \text{ radian}$$

When the grid and screen turns are aligned the beams transmitted through the control grid aperture will pass through the screen windings midway between the adjacent turns, and if the focusing action at the control grid is suitably contrived, the beam width at the screen plane will be relatively small; hence y is small, and the angular deflection is also small. If, however, the screen and grid turns are unaligned, y will have different values throughout the length of the tube, *i.e.*, y will depend on n where n is the aperture between the nth and $(n + 1)$th screen turns, counting from one end. Any value of y lying between $-1/2N_s$ and $+1/2N_s$ is equally likely, consequently, in summing up throughout the tube all the beam sections which enter the screen plane at an inclination θ_g, they will emerge over a range of angles lying between $\theta_g + \theta_{s\cdot max}$ and $\theta_g - \theta_{s\cdot max}$. Since θ_g can range in value from $-\theta_{g\cdot max}$ to $+\theta_{g\cdot max}$ the emergent electrons will range from: $-[\theta_{g\cdot max} + \theta_{s\cdot max}]$ to $+[\theta_{g\cdot max} + \theta_{s\cdot max}]$

Suppose that $I_g(\theta)$ represents the current transmitted through the grid with (reduced) angular deflection from $-\infty$ up to θ radians. Then, owing to the spreading out effect just described, the distribution-in-angle of the current leaving the screen plane will be:

$$I_s'(\theta_1) = \frac{1}{2\theta_{s\cdot max}}\int_{\theta_1 - \theta_{s\cdot max}}^{\theta_1 + \theta_{s\cdot max}} I'_g(\theta)d\theta \ldots \quad (2)$$

where $I_s(\theta_1)$ is the current transmitted through the screen with total angular deflections from $-\infty$ up to θ_1. $I_g'(\theta)$, $I_s'(\theta_1)$ are the differentials of $I_g(\theta)$, $I_s(\theta_1)$ with respect to θ and θ_1

respectively. The primary current reaching the anode will be equal to:

$$\int_{-\theta_1}^{+\theta_1} I_s'(\theta_1)d\theta_1$$

if limiting θ_1 is put equal to $\sin^{-1}\sqrt{V_m/V_1}$, *i.e.*, to $\sqrt{V_m/V_1}$ if V_m is small.

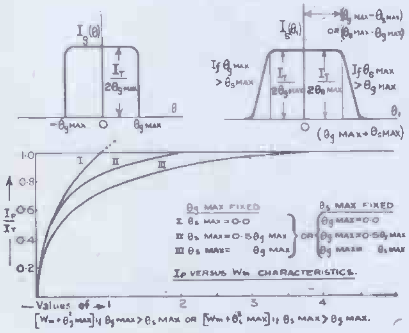

Fig. 13. Effect of deflections in modifying the anode current *v.* V_m/V_1 characteristic.

Now it is interesting to see that Equation 7.3.(2) converts a flat-topped rectangular distribution for $I_g'(\theta)$ into a trapezoidal distribution for $I_s'(\theta_1)$. Thus, although there is assumed to be a sudden jump to zero in $I_g'(\theta)$, there is no such sudden jump in $I_s'(\theta_1)$ and therefore there is no discontinuity in the slope of the anode current versus V_m characteristic, which could be supposed to correspond to a sharp knee voltage. This is illustrated in Fig. 13.

It is to be inferred, therefore, that because of cumulative deflections at the control grid and screen the maximum transverse velocity may be large, but at the same time the extremely deflected electrons are comparatively sparse, so that the I_A, V_m curve approaches the full current value gradually and without sudden changes in slope. The explanation of sharp " knees " must therefore lie in the properties of space charge.

(*To be concluded.*)

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Degassing of Light Metal Alloys by Sonic Vibrations

W. ESMARCH, T. ROMMEL and K. BENTHER

(W.V. Siemens Werke, Werkstoff Sonderheft, Berlin, 1940, pp. 78-87)

IT is well known that the passage of an ultrasonic wave in a liquid is accompanied by the formation of gas bubbles. These bubbles are partly due to the coalescence of microscopic bubbles already present in the liquid and are reinforced by previously dissolved gas being liberated in the low-pressure regions of the sound wave.

Kruger in 1931 took out a patent for degassing metallic melts by this method (German Patent No. 604486), ultra sonic waves being generated in the melt by a dipper controlled by a magnetostrictive oscillator. The main difficulty in this process was the provision of suitable material for the dipper. Ceramic materials rapidly disintegrated while metallic dippers only proved suitable in rare instances. In addition the process of wave generation in the melt is very inefficient, a considerable proportion of the energy of the oscillator being lost by reflexion at the surfaces of separation or absorbed by the dipper.

It appears that the only way of making the process commercially possible would be the generation of high-frequency waves directly inside the melt. Now in the high-frequency electric furnace, the heat production is due to the formation of eddy currents in the charge. These eddy currents, moreover, are subjected to electrodynamic forces due to the magnetic field of the furnace circuit and cause the well-known rotary motion of the melt in induction furnaces.

This rotary motion favours the absorption of air by the molten material and therefore counteracts to some extent the degassing effect of the rise in temperature.

By superimposing a steady magnetic field on the high-frequency field of the furnace (the resultant field being in the direction of the coil axis) mechanical vibrations can be induced in the melt, the force at each point being proportional to the product of the local current density and field strength and acting radially to the coil axis. Moreover, by suitable choice of bath dimensions, resonance effects can be produced which increase the intensity of the vibrations.

We thus have a method of generating high-frequency waves in the melt without the need of a dipper. On the other hand, the frequency range is restricted to that of the alternating current feeding the furnace.

The authors are, however, convinced from preliminary experiments that there is no advantage from the degassing point of view of employing frequencies in excess of 10,000/sec., provided that the intensity of the vibration is sufficient.

In their experiments, therefore, an A.C. generator of this frequency was employed for feeding the furnace coil, the average current consumption being of the order of 100 A. The superimposed steady magnetic field was produced by 450 direct current fed with the same coil, the D.C. generator being protected by the insertion of suitable chokes and condensers. The total energy consumption amounted to about 15 kW, of which 10 kW were supplied by the high-frequency generator. With a specially designed heating coil, the energy consumption for the steady magnetic field could have been reduced very considerably.

The experiments were carried out with 8-10 Kg. melts of pure aluminium and aluminium-magnesium alloys, the temperature being kept constant at 700° C. Samples were drawn off every 10 minutes and the gas content determined by the well-known vacuum method.

It appears that alloys containing even relatively large per cent. of Mg can be completely degassed by this method in 30-60 minutes, provided the surface of the melt is protected by a fused salt layer and that dry air or nitrogen is directed on to the surface during the treatment.

Suitable salts can be obtained from the I.G. under the trade names Hydrosal and Elrasal. A laboratory product utilised by the authors and giving equally good results has the following composition:—

KCl	40 per cent.
$NaCl$	30 per cent.
$CaCO_3$	15 per cent.
NaF	15 per cent.

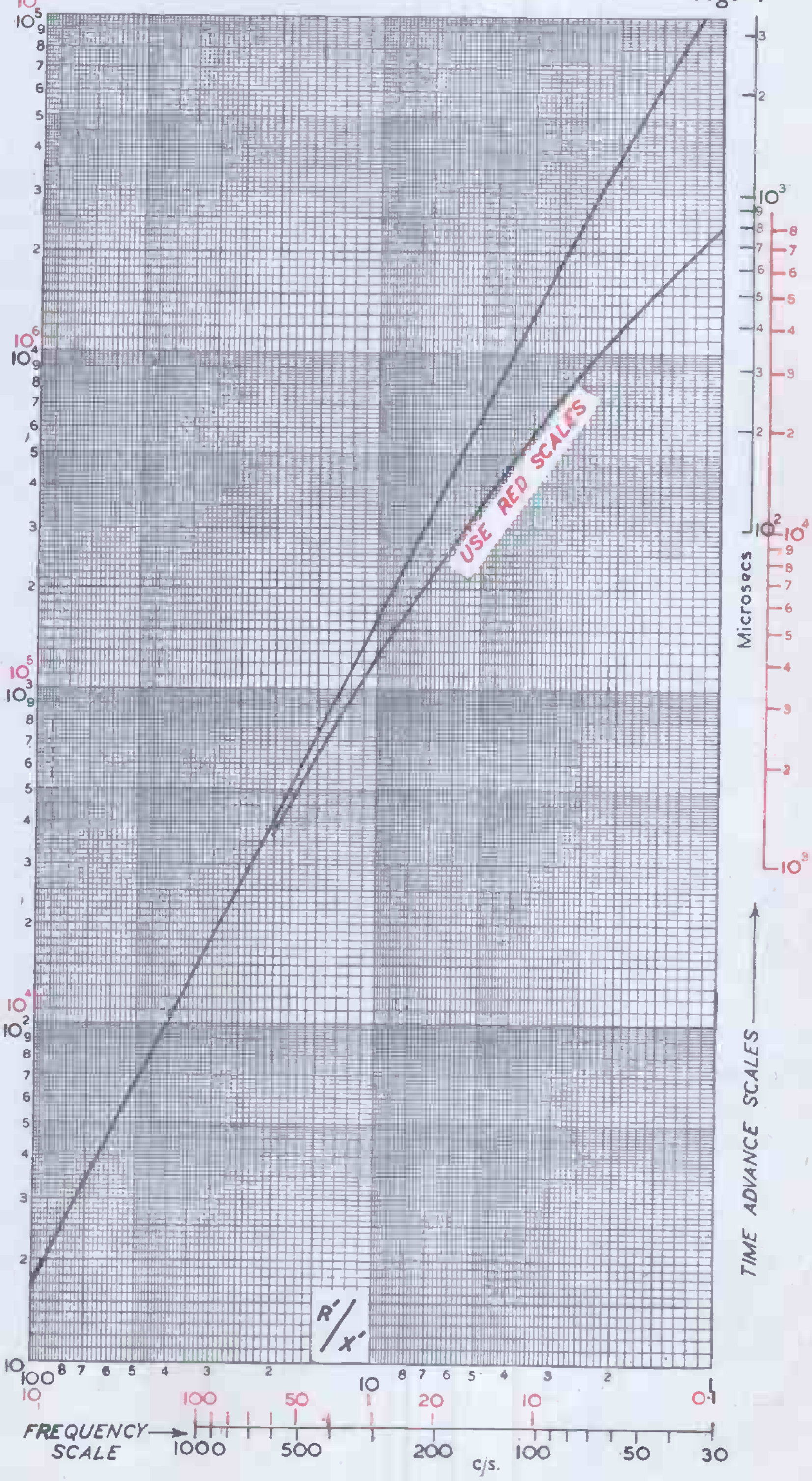
(By courtesy of R.T.P. Section, M.A.P.)

DATA SHEET

The Frequency Response of R.C. Coupled Amplifiers

By K. R. STURLEY, Ph.D.

Fig. 1



THE curves given in a concise form in this Data Sheet enable the overall frequency response and time delay to be obtained for a resistance-capacitance coupled amplifier in its pass frequency range.

They are derived from the expressions given in Part III of the author's articles on "Low Frequency Amplification" (ELECTRONIC ENGINEERING, January, 1945, p. 335).

Each curve is accompanied by a typical example, showing the method of obtaining the results. This example relates to a triode having the following circuit constants:

Amplification factor (μ)	50
Slope resistance (R_a)	50,000Ω
Anode load (R_o)	200,000Ω
Coupling capacitance (C_c)	0.005 μF
Grid leak of succeeding valve R_g	1.0 meg
Stray capacitance (C_s)	0.0005 μF.

Frequency Response

This is obtained from the curves overleaf (Figs. 2 and 3) relating to the low and high ends of the frequency range.

The calculation of the constants R', X', R'', and X'' is given in the table of symbols under the curves.

Phase Angle and Time Delay (Fig. 5)

The time delay of an amplifying stage is a function of the phase angle displacement of a given output voltage component relative to its input component of the same frequency after passing through the same stage.

Phase angle displacement is converted into time advance (ϕ_l) or time delay (ϕ_h) in microseconds by using the formula:

$$\text{Time advance or delay} = \frac{\phi^\circ \times 10^6}{360^\circ \times f} \text{ microsecs.}$$

where f is the frequency in c/s.

For calculating the curves the frequency corresponding to R'/X' or $R''/X'' = 1$ is assumed to be 1 c/s. At R'/X' or $R''/X'' = 10$ it is taken as 10 c/s.

To apply the curves to a particular case, the horizontal frequency scale is located so that f_{lo} or f_{ho},* calcu-

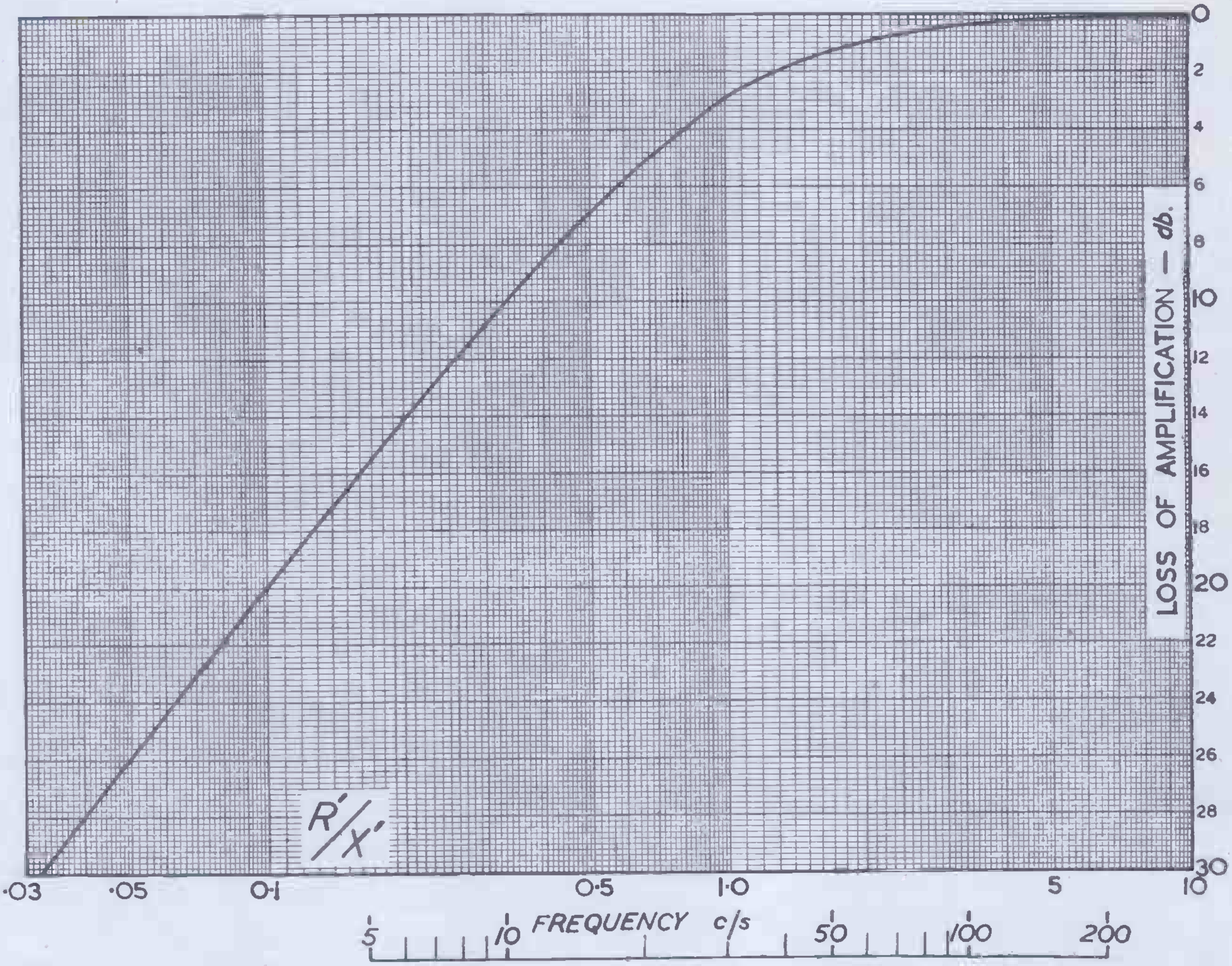
* f_{lo} is the low frequency at which the total equivalent resistance R' of the valve and anode circuit is equal to the reactance of the coupling capacitance C_c, *i.e.*, at which $R'/X' = 1$.

f_{ho} is the high frequency at which the total equivalent resistance R'' of the valve and anode circuit is equal to the reactance of the stray capacitances C_s, *i.e.*, at which $R''/X'' = 1$.

(*Continued on p.* 596.)

Low Frequency Response

Fig. 2



Formulae and Instructions

Loss of amplification at low frequencies compared with that at medium frequencies.

$$\text{Loss (db.)} = -20 \log_{10} \left| \frac{A_m}{A_l} \right|$$

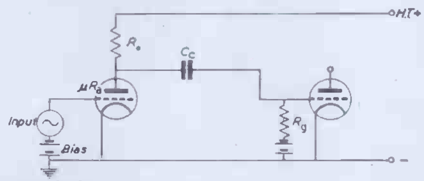
$$= -10 \log_{10} \left(1 + \left[\frac{X'}{R'} \right]^2 \right)$$

A_m = Amplification at medium frequencies

$$= \frac{\mu \dfrac{R_o R_g}{R_o + R_g}}{R_a + \dfrac{R_o R_g}{R_o + R_g}}$$

A_l = Amplification at low frequencies.

Calculate f_{10} as in Col. iii and set $f_{10} = \dfrac{1}{2\pi C_c R'}$ c/s. on the frequency scale against $R'/X' = 1$.



Symbols

μ = Amplification factor of valve.

R_a = Slope resistance of valve.

R_o = Anode load resistance.

R_g = Grid resistance of the succeeding valve.

X' = Reactance of the coupling capacitance, C_c.

$$= \frac{1}{2\pi f_1 C_c}$$

R' = Slope resistance of valve in parallel with the anode load resistance of the new valve plus R_g.

$$= \frac{R_a R_o}{R_a + R_o} + R_g$$

Example

$\mu = 50$, $R_a = 50{,}000\Omega$.

$R_o = 200{,}000\Omega$, $R_g = 1\text{M}\Omega$.

$C_c = 0.005\ \mu\text{F}$.

$$A_m = \frac{50 \times 166{,}666}{216{,}666} = 38.4.$$

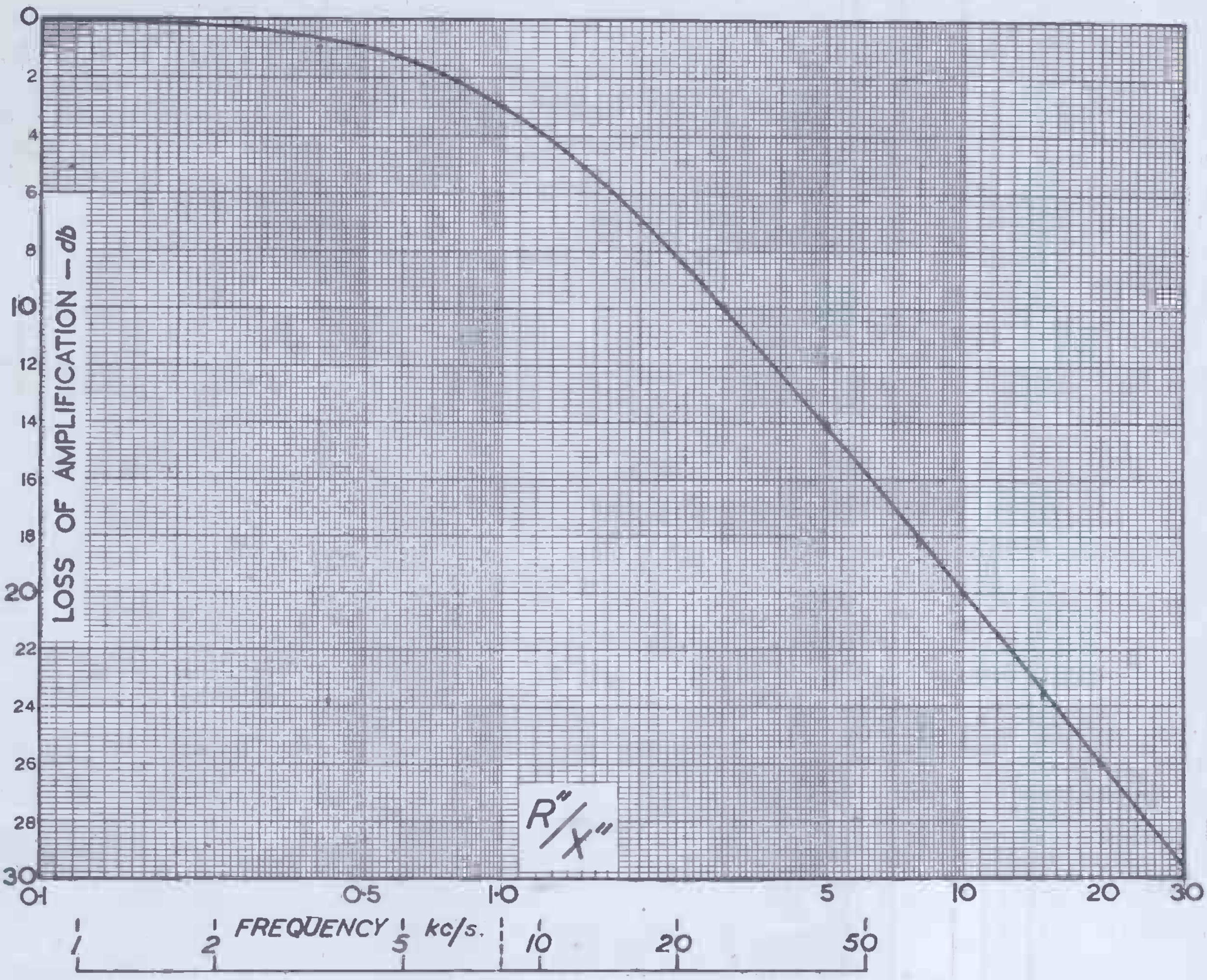
$$R' = 40{,}000 + 1{,}000{,}000 = 1.04\text{M}\Omega.$$

$$f_{10} = \frac{1}{2\pi C_c R'} = \frac{1}{6.28 \times 0.005 \times 1.04}$$

$$= 30.6 \text{ c/s.}$$

Thus loss at 50 c/s. is -1.4 db. and at 25 and 100 c/s. is -3.95 and -0.4 db. respectively.

Fig. 3 High Frequency Response



Formulae and Instructions

Loss of amplification at high frequencies compared with that at medium frequencies.

$$\text{Loss (db.)} = -20 \log_{10} \left| \frac{A_m}{A_h} \right|$$

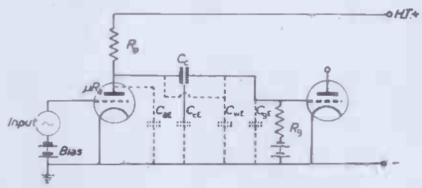
$$= -10 \log_{10} \left(1 + \left[\frac{R''}{X''} \right]^2 \right)$$

A_m = Amplification at medium frequencies

$$= \frac{\mu \dfrac{R_o R_g}{R_o + R_g}}{R_a + \dfrac{R_o R_g}{R_o + R_g}}$$

A_h = Amplification at high frequencies.

Calculate f_{ho} as shown in Col. iii and set $f_{ho} = \dfrac{1}{2\pi C_s R''}$ c/s. on the frequency scale against $R''/X'' = 1$.



Symbols

μ = Amplification factor of valve.

R_a = Slope resistance of valve.

R_o = Anode load resistance.

R_g = Grid resistance of the succeeding valve.

X'' = Reactance of total stray capacitance, C_s, across the anode circuit to earth

$$= \frac{1}{2\pi f_h C_s}$$

$C_s = C_{aE} + C_{wE} + C_{cE} + C_{gE}$

C_{aE} = Valve anode-earth capacitance.

C_{wE} = Wiring-earth capacitance.

C_{cE} = Capacitance to earth of C_c.

C_{gE} = Input grid-earth capacitance of succeeding valve.

R'' = Value of slope resistance, load resistance and grid input resistance (assumed to be the grid leak, R_g) of the next valve all connected in parallel

$$= \frac{R_a R_o R_g}{R_a R_o + R_a R_g + R_o R_g}$$

Example

$\mu = 50$, $R_a = 50{,}000\Omega$.

$R_o = 200{,}000\Omega$, $R_g = 1\text{M}\Omega$.

$C_s = 0.0005\ \mu\text{F}$.

$$A_m = \frac{50 \times 166{,}666}{216{,}666} = 38.4.$$

$R'' = 38{,}500\Omega$.

$$f_{ho} = \frac{1}{2\pi C_s R''} = \frac{10^6}{6.28 \times 0.0005 \times 38{,}500}$$

$= 8{,}260$ c/s.

Thus loss at 5,000 and 10,000 c/s. is -1.35 and -3.9 db. respectively.

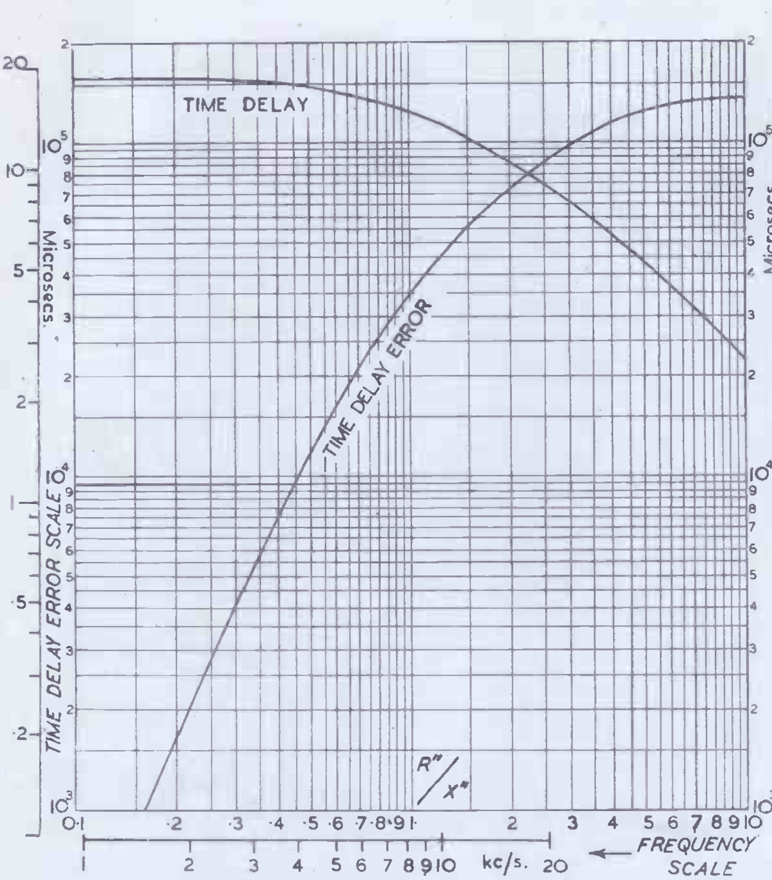


Fig. 4

lated as in the example, registers with the ordinate R'/X' or $R''/X''=1$.

A vertical logarithmic time advance or delay scale of the same dimensions as the abscissa scale has also to be located, so that $\frac{125{,}000}{f_{10}}$ or $\frac{125{,}000}{f_{ho}}$ microsecs. time advance or delay registers with the abscissa 125,000. Thus on Fig. 1 a time advance of 4,080 microsecs. registers with the abscissa 125,000 and we read time advances of 1,720 and 472 microsecs. at 50 and 100 c/s. respectively. On Fig. 4 a time delay of 15.1 microsecs. registers with the abscissa 125,000 and we read off 17.2 and 14.2 microsecs. at 5,000 and 10,000 c/s. respectively.

Time Delay Error Curve (Fig. 4)

Fig. 4 shows that for the high frequency part of the range the time delay is almost constant at 159,000 microsecs. up to $R''/X'' = 0.5$. It is thus possible to construct a time delay error curve of general application by plotting the difference between 159,000 microsecs. and the time delay curve of Fig. 4.

This time delay error curve is given in Fig. 5.

The vertical logarithmic time delay error curve represents an advance error because the frequency component is insufficiently delayed. The actual error is obtained by locating a logarithmic time error scale, so that $\frac{34{,}000}{f_{ho}}$ microsecs. registers with the abscissa 34,000 microsecs. (the error at $R''/X'' = 1$). In our example $\frac{34{,}000}{8{,}260} = 4.11$ microsecs. on the sliding scale is located against 34,000 microsecs. on the fixed abscissa scale, and time errors of 1.95 and 5.3 microsecs. are read at frequencies of 5,000 and 10,000 c/s. The importance of Fig. 4 lies in its application to television transmission because it provides a measure of the displacement and blurring of the fine detail of the picture.

It is not possible to construct a similar curve for the low frequency end of the range since time advance steadily increases as frequency is decreased and is infinite at zero frequency.

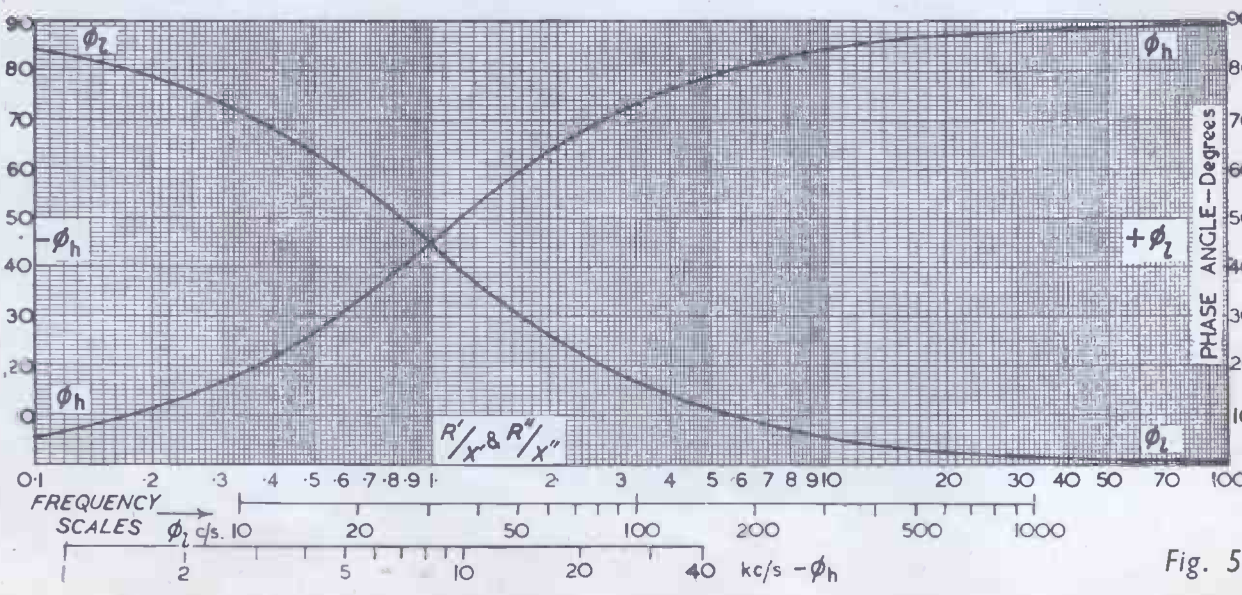


Fig. 5

METASTABLE

A patented Metalastik suspension system having many valuable applications

This system is extensively used in the vibration-insulating mountings of instruments and other important apparatus.

As the drawing shows, the supports are so located that their main axes of resistance pass through the centre of gravity.

Thus, disturbing effects in all directions are elastically cushioned in a controlled manner which imparts stability and prevents 'flop'.

The resilient mountings support the load, without tilting, by compression, with deflection characteristics which limit the range of movement.

The smaller diagram shows the undesirable result of using resilient mountings without adequate study of the basic principles involved.

Metalastik experience and collaboration is at the disposal of all who have problems arising from vibrations of any frequency or amplitude, known or unknown.

METALASTIK

LTD., LEICESTER

Tropic-Proof Radio Apparatus

Part 3

By W. J. TUCKER

RADIO frequency tuning coils transformers and chokes are more sensitive to attack by moisture than the inductances used in power-frequency circuits.

In the latter the requirements are that a high insulation resistance is maintained and breakdown is prevented between high voltage points. In radio frequency circuits the efficiency of the coil as part of an inductance-capacity circuit must also be kept at the proper level. Variable efficiency will lead to unreliable performance and instability.

Developments in the production of low loss insulating materials for coil formers have enabled the radio industry to produce high efficiency coils for all frequencies, but the advantages of the improvements which have been made in the design of high-Q inductances are lost if moisture is allowed to penetrate into the windings.

It has been shown that in humid conditions the Q of unprotected coils drops very rapidly, often to as low as a tenth of the value of a coil which is thoroughly dry. Moisture penetration leads to deterioration of wire-covering and interleaving materials, and encourages the growth of fungus. The insulation resistance between coils and terminal plates drops considerably after a few hundred hours' exposure to a damp atmosphere.

The use of materials which are not susceptible to attack by moisture is one way of improving the service life of coil assemblies, and in this connexion it should be noted that all forms of cellulose covering or interleaving are definitely unsatisfactory.

In the opinion of some authorities the use of a cellulose acetate film for interleaving between windings is a satisfactory method, and it is certainly far better than any fabric materials, varnished or otherwise, for the purpose.

Cotton, paper and viscose rayons are definitely unsuitable for interleaving or wire covering.

To resist the effects of moisture penetration it is customary to treat coils with a protective compound. It follows that any such compound must possess electrical properties which are equal to those of the other insulating materials employed in the construction of the inductance assembly.

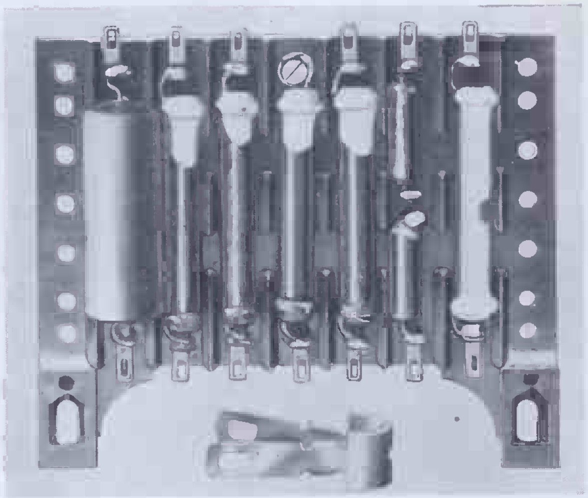


Fig. 4. A moulded group board designed and used by Messrs. A. C. Cossor Ltd. The special soldering tag for insertion in the board is shown below

Both wax and varnish compounds are used as protective coatings and at the present time there is much controversy over the relative merits of each of these classes of material. Whichever material is used a process of thorough impregnation must be adopted. Merely applying an outer protective coat is not an effective way to seal against moisture penetration.

In favour of waxes it can be said that they penetrate well and form a thick pliable coating of high electrical efficiency at radio frequencies. They are also easy to apply. The opponents of waxing processes, however, hold that waxes are only suitable for use over a limited temperature range and most of the types at present available have a soft surface which is receptive to the accumulation of dust and other impurities, which form a thin surface film which absorbs moisture. Surface leakage is thus increased. It is also pointed out that it is difficult to make wax adhere to metal and other such smooth surfaces with the result that a leakage path for moisture penetration is always formed where the wax is insufficiently bonded to connecting wires and tags.

Tests carried out on waxed coils show that, despite the excellent electrical characteristics of waxes, most of the above objections are substantiated. It is also proved that certain waxes, particularly those of vegetable origin, encourage the growth of fungus.

Varnishes form a more durable coating and can be exposed to severe variations of temperature without having their efficiency as a waterproofing medium impaired by such exposure. The electrical properties of most varnishes, however, are inferior to those of the waxes. Furthermore, varnishes form a hard brittle surface which is easily cracked by the flexing of connecting wires and by vibration.

Recent developments in the production of waxes have led to the introduction of improved mineral waxes which possess a hard durable surface over a wide temperature range.

Tests are in progress on mixtures which include proportions of polyisobutylene, polythene and chlorinated naphthalene, and the results obtained so far are very promising.

The author's view is that waxes, although at present viewed with disfavour in many authoritative quarters, will be more acceptable if they can be made to present a tougher surface and can also be made to adhere more satisfactorily to metal. Ninety per cent. of the breakdowns occurring with waxed coils are due to the penetration of moisture through the gap between the connecting wires and the inner surface of the wax coating.

The only completely satisfactory way to protect radio-frequency coils is to hermetically seal them in metal cans, using a technique similar to that described for power transformers and chokes.

There are, however, many snags in connexion with completely sealing these coils. Iron-cored types of high Q need adjustment in various stages of assembly, and intermediate frequency assemblies incorporate trimming capacitors which must be readily accessible for adjustment. In many instances, therefore, complete sealing is not practicable and it is therefore necessary to fall back on wax or varnished impregnation or a combination of both.

One very satisfactory way to solve the problem of waxes versus varnish would be to wax-impregnate the coils and subsequently dip or spray them with varnish. No doubt this will be done as soon as a varnish which is suitable for application over a wax is developed.

When waxed or varnished coils are enclosed in screening cans, the latter should be adequately ventilated to provide drainage for the moisture which collects as a result of condensation. If it is not possible to seal against the ingress of moisture, steps should certainly be taken to prevent an accumulation of water to remain adjacent to the coil.

Variable Resistors

The variable resistor illustrated in the first article in this series (May, 1945) is offered by the Morgan Crucible Co., Ltd., as a fully tropical component. This resistor is very extensively used at the present time, and is successful because of the care taken to ensure that the materials used are as corrosion-proof and stable as possible, and the moulded cover forms an adequate seal against moisture penetration. Various other features have been incorporated in variable resistors. One improvement is the addition of a pair of neoprene rings on the rotating spindle. These rings are let into grooves in the spindle and press against the inner wall of the bush, thus forming an effective seal against moisture percolating along the spindle into the interior of the component.

Wire-wound variable resistors give trouble when the former, used for the resistance winding, is made of fabric-base synthetic resin sheet. This material absorbs moisture and, when thin sheets are used, the distortion which takes place is sufficient to throw the resistance winding out of alignment with the contact arm. As the distortion increases, so the spindle arm becomes more difficult to operate. The final outcome is a complete seizure. An improvement in the design of wire-wound resistors can be made by using moulded or ceramic formers; the latter material is preferable. Alternatively, a sealed type of construction should be adopted. A number of manufacturers in this country are at present developing completely sealed types.

Fixed Resistors

Fixed resistors of the carbon type are subject to wide variations in value when exposed to humid conditions, but complete stability is usually only required in special instances, and most carbon resistors are acceptable to limits of ± 10 to 20 per cent. High stability resistors are made by sealing the element in a glass tube with metal end disks which are soldered to the glass. In order that this soldering can be carried out the ends of the glass tube are metallised with a silver deposit.

Variable Capacitors

Air-dielectric tuning capacitors give very little trouble. Faults which do occur are usually attributable to fungus growth between fixed and moving plates and to corrosion on unprotected brass parts. Other causes of reduced efficiency are corrosion on the bearings and surface leakage across insulating spacers and end plates. Some synthetic resin bonded laminated paper sheets absorb moisture to a degree serious enough to make them unreliable as a spacer for capacitors, and glazed ceramic is a preferable material. Glazing is specified because the surface of unglazed ceramic absorbs moisture.

Mica dielectric compression capacitors have been found to be unsatisfactory in many instances. Air-spaced or enclosed ceramic trimmers are preferable.

Tuning dial and pointer mechanisms, however, are particularly susceptible to failures most of which are caused by the use of unsuitable materials.

Twine or cord used for pointer mechanisms must be treated to stop rotting and prevent the growth of fungus. Special "dopes" are now available for this purpose.

Springs must be treated to prevent rust. A rusty spring soon fails to provide the right degree of tension or compression. On the pulley and pointer type of indicating mechanism springs play a vital part in the design and the failure of these will stop the mechanism from working. Scales and transparent windows must be made of materials which will not warp when wet. Cellulose acetate windows are definitely unsuitable. Transparent urea-formaldehyde plastic (Beetle Scarab or "Mouldrite") windows are more satisfactory. Methyl-methacrylate (Perspex) is also more suitable than the acetate product. Scales if painted on metal should be produced with a paint which remains adherent to the metal in very humid conditions, and when exposed to a temperature of 40°-50° C. For opaque scales a method of solving the problem of long service life is to utilise the specially marked resin bonded paper laminate

Fig. 1.

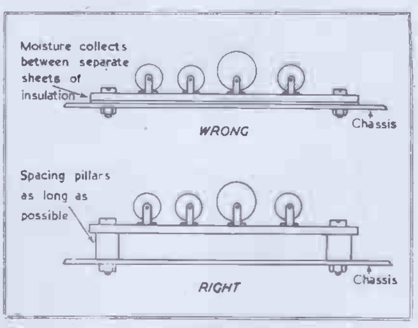


Fig. 3. The wrong and right way to assemble component group boards.

Fig. 2.

material (Bakelite, Tufnol, Paxolin, etc.) which is processed by the Universal Engraving Co., Ltd. Samples of labels and scales produced by the company have been subjected to 1,500 hours' tropical test (95 per cent. humidity 25°-40° twenty-four hours continuous cycle) and have not shown any signs of deterioration or fading after this period.

Fixed Capacitors

To deal adequately with the subject of fixed capacitors and their suitability for tropical use would entail writing a special article on the subject. There are so many existing types to be considered and an almost equal number of new and improved types ready to come off the production line.

The present position is that paper tubular condensers protected only by the wax are being replaced by metal-encased types with synthetic rubber end seals, and an even later development is the glass-encased type with a silvered-glass seal to metal; silvered-mica wax-protected types are being replaced by ceramic or moulded types; and various miniature types of tubular construction are being made available. Capacitors of higher value than obtainable in any of the foregoing forms are still being made in rectangular metal cases, but it is generally recognised that 100 per cent. efficiency can only be obtained with ceramic bushes for lead-out connexions. Trouble has been experienced due to moisture penetration around and through the moulded plastic type of terminal bush.

Wax finishes are now unpopular because of the difficulty of getting wax to maintain a good seal when subjected to the combined effects of humidity and vibration. Moulded capacitors must be made with a material which has a very high resistance to the penetration of water vapour and mica-filled compounds are best in this respect. Also great care must be taken to ensure that an effective seal is made where the connecting wires leave the body of the moulding. Many breakdowns have been attributable to moisture penetration along these wires. It is advisable to apply a coat of varnish over all moulded capacitors, particularly at the points mentioned, after the component has been assembled and wired in its final position in the equipment.

The best type of moulded capacitor is one in which the plate assembly is immersed in wax and then enclosed in the moulded outer cover. Since this wax is not exposed to the atmosphere it need not be judged or rejected by the considerations set out against the use of wax as a protective agent.

Electrolytic capacitors are almost all enclosed in metal cases and are satisfactory provided that sealing is adequate and they are not exposed to extreme cold (which causes a drop in the capacity value) or a high temperature, which will dry out the active elements and reduce the life of the component.

Gramophone Pick-Ups and Earphones

On both these components failure is usually due to low insulation resistance from coils to frame or metal work. General deterioration is caused by fungus growth on unprotected coils, collapse and distortion of acetate bobbins, corrosion on magnet and pole pieces, and with pick-ups, perished rubber buffers around the armature assembly. Earphone cases when made of a zinc alloy corrode very badly, and the zinc-oxide which is formed powders off and interferes with the free movement of the vibrating disk.

Figs. 1 and 2 show a pick-up and an earphone assembly after 1,000 hours' tropical test (95 per cent. humidity 25° C.-40° C. continuous 24-hour cycle). No fungus is evident on these samples because they were tested for resistance to humidity only.

Component Group Boards, Panels and Valveholders

It is in connexion with these component parts and the methods of assembly by which they are incorporated in receiving and transmitting equipment that the most sweeping changes will have to be made in present practice.

The most popular method of assembling resistance and capacitors is to mount them on a board made of synthetic resin bonded sheet (Bakelite, Tufnol, Paxolin, etc.), into which soldering tags have been eyeletted. This assembly method is satisfactory only if paper (not fabric) laminated material is used, spacing between tags is adequate and the complete board is stood away from the chassis or other adjacent surface by at least $\frac{1}{8}$ in.

A common method of assembly is to provide a thin backing or insulating plate which is affixed to the rear face of the tag board and then mount the complete assembly flat on the chassis. This is a highly dangerous practice. Moisture is trapped between the rear of the tag board and the insulating plate, and very soon causes surface leakage and tracking between the connecting tags. Many cases are on record of equipment which has ceased to function as a result of leakage and breakdown on group board sub-assemblies. The correct and only way to mount these boards is to space them away from the chassis, deleting the backing plate altogether. The right and wrong assembly methods are illustrated in Fig. 3. Some radio firms have developed their own types of group board. One of these, a product of A. C. Cossor, Ltd., is illustrated in Fig. 4.

This panel is moulded, and as will be seen is designed so that the maximum leakage path exists between tags. The layout and construction is arranged so that the panel is mounted to stand at right angles to the mounting surface.

Valveholders made up of sandwiched synthetic resin bonded laminated material are unsatisfactory, and should never be used. Moisture collects between the sandwiched material, and cause surface leakage and tracking. Moulded valveholders are more satisfactory, and for high frequency circuits loaded polythene and ceramic types give good service. With phenolic moulded valveholders there is the ever-present danger of tracking due to accumulation of fungus and moisture. The voltage handled by ordinary receiving valves is quite adequate to start a "track" across from one pin to another, and many instances of breakdown are attributable to this type of fault. One way of overcoming this is to use valveholders moulded with a non-track material, such as the urea-formaldehyde resins (Scarab) or Panilax.

We have now dealt with all major components, and are left with only miscellaneous items, finishes, general wiring and assembly details to discuss. These will be dealt with in the next and final article in this series.

An Electronic Musical Instrument

With a Photo-Electric Cell as Playing Manual

By W. SARAGA, Dr.Phil.

This paper, from which the following is an abstract, was delivered at a meeting of The Electronic Music Group which was held on May 12, 1945

In this article a " first model " of an electronic musical instrument is described which the author built some years ago. Like Martenot's[1] " Ondes Musicales," Theremin's[2] " Aetherophon " and Trautwein's[3] " Trautonium," it is a homophonic or single-note instrument possessing an electronic audio-frequency generator, the output current of which produces in a loudspeaker a musical tone; the player controls pitch and loudness of this tone by varying frequency and amplitude of the audio-frequency current.

A photo-electric cell is used as playing manual for controlling the pitch, the amount of light falling on this cell determining the frequency of the oscillation produced.* Thus the player can play on this instrument by varying the amount of light falling on the cell by moving his hand between the cell and a source of light. This playing technique is in some aspects similar to that employed in Theremin's instrument; but there are some important differences which will be discussed, and it is hoped that the new playing technique will provide players and composers with new, hitherto unknown or technically impossible, methods of expression.

The loudness of the tone produced can be controlled by means of a pedal which actuates a variable resistance or potentiometer. In a more elaborate form of the instrument it is intended to control the loudness by varying the amount of light falling on a second photo-electric cell. It is expected that this method of loudness control will be useful also in connexion with other electronic musical instruments.

For starting and stopping the tone the player uses a switch held in one hand which opens or closes the loudspeaker circuit. This switch is necessary because the loudness control by means of a pedal is rather slow. Instead of using a switch the player can close the loudspeaker circuit by touching two metal contacts with his hand, using the hand as a conducting link.

With photo-electric loudness control it will probably be possible to dispense with special start-stop control devices. At the same time photo-electric loudness control will provide the player with a very flexible means to alter at will the starting and decaying characteristics of his tones.

The audio-frequency oscillations generated in the instrument in its present form are very rich in harmonics and therefore the timbre of the tones produced can easily be modified by emphasising or eliminating certain harmonics or groups of harmonics; for example, by employing formant circuits in the way described by Trautwein.[3] However, the object in designing the new instrument was to obtain experience with the new method of playing made possible by employing a photo-electric cell as a playing manual. The timbre of the tones produced is, at present, more or less accidental and therefore of secondary importance.

Musical Object of the Photo-Electric Cell Instrument

In Theremin's Aetherophon two supersonic valve oscillators are used to generate in a mixer circuit the required audio-frequency current. Since a small relative frequency variation of one of the supersonic oscillations produces a much larger relative frequency variation of the audio-frequency current, the pitch of the tone produced by the instrument can be controlled by a comparatively small variation of the tuning capacitance of one of the supersonic oscillators. This variation of capacitance is performed by the player by varying the distance of his hand from a metal rod which forms part of the tuning circuit of this oscillator.

Theremin had a definite musical aim in building such an instrument. He is of the opinion that the player of a musical instrument, when trying to express his musical intentions, has to struggle with the instrument, to overcome its resistance and inertia. Therefore, as Theremin believes, there is always a gap between the intentions of the player and the music actually played. Theremin set himself the task of finding means to reduce this gap and he believes this can be done if the player is given an instrument which requires a movement of the player's hand in the air only.*

However, practical experience with Theremin's instrument shows that its playing technique, while relieving the player from the resistance and inertia of the instrument, increases the resistence and inertia of his own hand because the hand has to be moved freely in the air for long periods without any physical support and without any visible indication of the correct positioning of the hand. Moreover, the pitch produced depends not only on the position of the hand but, to a smaller degree, also on the position of the whole body. Furthermore, the character of the electrostatic field of the rod in which the player moves his hand is such that it is very difficult to produce a linear pitch scale, *i.e.*, to make the pitch proportional to the distance of the hand from the rod.

The object of the new instrument described in this article is to eliminate these disadvantages of Theremin's instrument. For this purpose the use of a photo-electric cell as playing manual for determining the pitch or the loudness of the musical tones† seems to be particularly convenient, because the geometrical relations of light beams and light and shadow which determine the amount of light

* The use of a photo-electric cell as a manual for controlling the oscillator of the instrument, as described above, should not be confused with the well-known use of a photo-electric cell as part of a photo-electric scanning generator in some electronic organs

* Many musicians hotly contest the basic idea of this argument. They believe that " fighting against matter " is the very basis of true art. Without taking sides in this argument, we can state the fact that Theremin has done pioneer work in the field of new playing techniques and his example has started a great amount of interesting experimental work in this field. Only the future will show whether musicians, composers as well as performers, will make use of these new playing techniques and thus ultimately justify their creation.

† Martenot seems to have been the first who has had the idea that a photo-sensitive device might be used as a manual in an electronic musical instrument. In a patent specification[13] which deals with various types of variable condensers, coils and resistors for controlling the pitch or the loudness of the tones produced in such instruments he briefly mentions that a selenium cell can be used as one such type of variable resistor. Martenot has become very well known in the field of electronic music by instruments based on other ideas[11, 12, 14] originally published in the same patent specification, but it seems that he has never pursued his idea of employing a selenium cell as manual any further.

falling on the cell when the hand of the player is in a certain position are much simpler, and much easier to control, than the geometrical relations of electrostatic fields which determine the hand capacitance in a certain position of the hand.

Technical Principles of the New Instrument

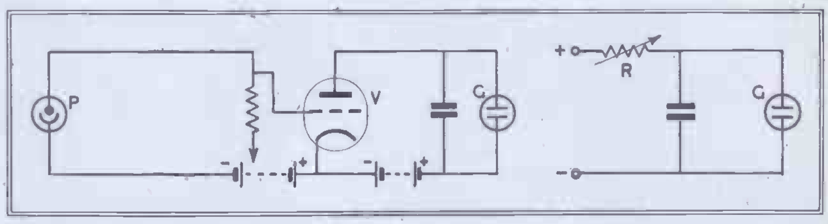
The primary effect produced by variation of the amount of light falling on a vacuum or gas-filled cell is a corresponding variation of current. If the cell is used in series with an ohmic resistance and fed by a d.c. battery, the effect is a variation of the voltage drops across cell and resistance.

This primary variation of voltage has to be used for controlling the frequency or amplitude of the alternating current produced in the audio-frequency generator of the electronic musical instrument. The problems here involved are similar to two well-known problems in communication engineering: (1) modulation, controlled by a modulating signal voltage, of the frequency of an oscillator; (2) amplitude control in amplifiers in accordance with a given control voltage.

The instrument actually built by the author employs a photo-electric cell manual for pitch control only, and an ordinary potentiometer pedal for loudness control. The variation of the d.c. resistance of a valve controlled by the primary photo-electric voltage variation is used to vary the frequency of a relaxation oscillator, the frequency of which depends on the value of resistance and capacitance employed.

The basic circuit of the instrument is shown in Fig. 1. It can be derived from an ordinary glow-lamp relaxation oscillator (Fig. 1a), in which the resistance *R* is replaced by a valve V. If the amount of light falling on the cell increases, the current flowing through the cell increases. Therefore, the grid voltage of the valve V becomes more negative and the d.c. resistance of the valve increases, lowering the frequency of the tone produced in the relaxation oscillator.

In the first experiments carried out by the author[8] the photo-electric cell was laid on a white sheet on a table in diffuse daylight, and the player covered a smaller or greater portion of the cell with his hand. This gave too much ambiguity in the relation between pitch and distance of the hand from the cell, and in further experiments the cell was put into a box of the shape shown in Fig. 2



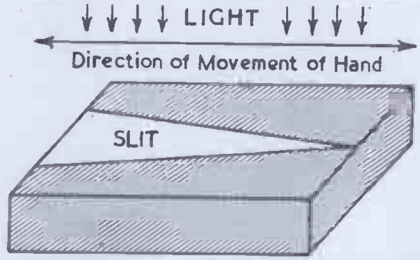


Fig. 1 (above). Basic circuit of the instrument, derived from the glow-lamp relaxation oscillator shown on the right (Fig. 1a).

Fig. 2. Box for controlling light incident on the photo-cell.

which the light can enter through a slit only; the interior of the box was painted white and the position of the cell was so chosen that indirect and diffuse light only could fall on it.

It was also found that, because of its inconstancy, it is not practicable to use daylight for operating the photo-electric cell.

The "First Model"

Based on the experience obtained during the experiments described above, a "first model" of a musical instrument possessing a photo-electric cell manual was built. This model consists of three units:

(1) A main case with attached lamp reflector, enclosing the audio-frequency generator, its high tension battery (150 volts), its low tension accumulator (4 volts), and the photo-electric cell (in a separate compartment).

(2) A pedal for loudness control, actuating a potentiometer.

(3) A start-stop switch, operating in the output circuit of the oscillator (alternatively two metal rails, preferably along the light slit, which can be electrically connected by the hand of the player).

The pedal and the switch are connected to the main case by flexible leads. The output terminals of the instrument have to be connected to an audio-frequency amplifier feeding a loudspeaker (use can be made of the amplifier and loudspeaker contained in any wireless receiver set).

For a musical instrument a pitch range between the lowest possible and the highest possible tone of at least three to four octaves appears desirable. The highest tone is produced by the instrument when no light is falling on the cell and the lowest tone is produced when the maximum amount of light available is used. Since a very weak source of light (one to three 4-volt incandescent bulbs) is employed, it is necessary, in order to obtain the desired range, to make the photo-electric cell circuit very sensitive. This can be done by making the resistance in series with the photo-cell very high; its actual value (50 megohms) depends, of course, on the type of cell employed. That part of the circuit which comprises the cell and this resistance has to be screened very carefully in order to prevent it from causing a high noise level. For the sake of simplicity the complete circuit has been screened by using a metal case for the whole set.

There is a slit on the top side of the case through which light can fall into the compartment containing the photo-cell.

The slit is very narrow in order to exclude, as far as possible, any light not coming from the lamp attached to the set. Moreover, an adjustable screen is provided along one side of the slit, and the instrument should be set up in such a position that the main light source in the room is screened off from the slit. The cell employed is red-sensitive which provides an additional protection against daylight. Stray light falling on the cell from an incandescent bulb fed by 50 c/s. current, in addition to varying the direct current output of the cell, would produce a 100 c/s. hum in the output. This hum can be practically eliminated by shunting the 50 megohm resistance with a condenser of 0.0001 μF; if a larger condenser were used, the pitch would not follow instantaneously the movement of the hand of the player. The width of the slit can be decreased and its contour can be altered by means of hard paper sheets which can be shifted, and fixed in any desired position, on the slit plate.

The circuit of the "first model" shown in Fig. 3, which is basically

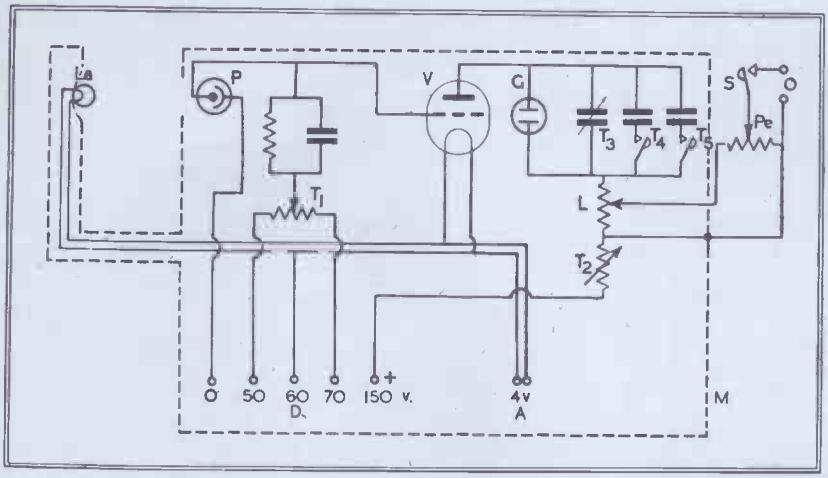


Fig. 3. Complete circuit of the instrument. La = Lamp. P = Photo-cell. G = Glow-lamp. Pe = Pedal control. S = Start-stop switch.

the same as the circuit in Fig. 1, comprises a number of variable circuit elements which enable the player to adjust and tune the instrument. These elements are designated as L and T_1, T_2, T_3, T_4, T_5. L is the level control, a variable potentiometer, by means of which the maximum loudness (when the pedal potentiometer is in its maximum position) can be adjusted. T_1, T_2, T_3, T_4, T_5 are tuning controls. The condensers T_3, T_4, T_5 transpose the pitch range, *i.e.*, the range within which the pitch can be controlled by varying the amount of light falling on the cell without any substantial change of the interval between the lowest and the highest tone. The variable resistance T_2 can be used to vary this interval. If $T_2 = 0$, the variation of the resistance of the valve V has the greatest effect on the frequency and therefore the maximum interval is obtained; the larger T_2 is made, the smaller becomes the effect of varying the resistance of V and the smaller the maximum interval. The variable potentiometer T_1 can be used for altering the grid bias voltage of the valve. In this way the shape of the curve representing the d.c. resistance of the valve as function of its grid voltage, and therefore also the shape of the curve representing the pitch of the tone produced as function of the position of the hand, can be altered. By adjusting the controls T_1 to T_5 as well as the width and the shape of the slit and the position of the lamp, a linear pitch scale can be obtained, *i.e.*, the logarithm of frequency becomes a linear function of the displacement of the hand.

The pedal is so arranged that, if no pressure is exerted by the foot, the loudness is a minimum; if the pedal is pressed downwards, the pedal potentiometer increases the output correspondingly. A strong spring turns the potentiometer back to its minimum loudness position as soon as the pressure on the pedal is discontinued.

The start-stop switch is of the bell push-button type. It can be held in the hand, attached to the case of the instrument. In order to avoid a clicking noise when the switch contact is being closed, a piece of felt, soaked with turpentine, is inserted between the two metal plates of the contact.

No provision has been made in the present model for a variation of tone colour or timbre. However, timbre control equipment could easily be added if and when so desired. The lack of such equipment in the present model does not mean that the character of the tones produced by it cannot be altered at all. The character of a musical sound does not depend on its steady state qualities (*i.e.*, its timbre) only, but also on its starting and decaying characteristics. These characteristics, though depending on the type of instrument employed, are to a very high degree under the control of the player.

Practical Results

The author, not being a musician, depends on the collaboration of musicians, players as well as composers, for a study of the musical features of the instrument, therefore very little can be said at present about practical results. The player can move his hand either on the slit plate or in the air above the plate. In the first case the position of the hand itself, in the second case the position of the shadow of the hand, determines the pitch produced. A kind of gliding over the slit plate without any pressure, but feeling the plate and making use of its support if so desired, is probably the most comfortable mode of playing. The performer may also hold a piece of stiff paper in his hand and play with the shadow of the paper. This has the advantage that the piece of paper can be made to have a straight edge which the human hand has not; however, holding a piece of stiff paper keeps the fingers in not too comfortable a position, which may adversely affect the delicacy of control.

It is easy to learn to play simple tunes, and tremolo passages as well as trills can easily be produced. After the player has learnt to co-ordinate the movements of his hands (one determining the pitch and the other operating the start-stop switch) he will be able to play not only glissando but also legato and staccato. It must, however, be emphasised that considerable training, corresponding to the training a violinist would need, will be necessary before a high technical standard of playing can be attained. It is not the purpose of an electronic musical instrument to make training superfluous.

References

1 Martenot's Instrument is mentioned in [11]; further details in [12], [13] and [14].

2 Theremin's instrument is briefly described in [11] and [15]; further details in [16], [14] and [17].

3 Trautwein's instrument is briefly described in [11] and [15]; further details in [18] and [19].

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Correcting for Voltmeter Load

A method of allowing for the error introduced by measuring voltage with current-operated meters

It is often necessary to find out the voltage, under working conditions, between two points in a D.C. circuit, when the only available voltmeter gives incorrect readings because of the effect of its connexion to the circuit.

By taking two readings, one with the voltmeter connected normally and the other with a resistance in series with the voltmeter, the "working" voltage can be deduced.

Two methods, described below, called the "fixed resistance" and the "variable resistance" methods, enable this to be done. Theoretically, the results can only be trusted if the apparatus contains sources of e.m.f. which can be regarded as constant sources in series with ohmic resistances, and resistances to which Ohm's law can be applied (linear resistances). In practice, however, the results will usually be sufficiently accurate when dealing with apparatus which contains rectifying valves. The reason for this is that, over the greater part of its working range, a rectifier can be represented approximately by a constant resistance in series with a source of constant e.m.f.

The "Fixed Resistance" Method

Let the resistance "looking in" to the two points be R ohms and the working voltage (that is, the voltage with the voltmeter disconnected) be V volts.

Then, by Thevenin's theorem, the apparatus behaves (as far as can be ascertained by measurements at the two points only) as a resistance-less source of e.m.f. V in series with a resistance R.

Let the resistance of the meter be M.

The voltage between the points when the meter is connected will be $VM/(M+R)$; call this V_1. Now repeat the measurement with an added series resistance equal to that of the meter (M).

The voltage read will be $\dfrac{VM}{2M+R}$, call this V_2.

We have

$$V_1=\frac{VM}{M+R} \qquad V_2=\frac{M}{2M+R},$$

or

$$\frac{1}{V_1}=\frac{1}{V}\cdot\frac{M+R}{M} \qquad \frac{1}{V_2}=\frac{1}{V}\cdot\frac{2M+R}{M}.$$

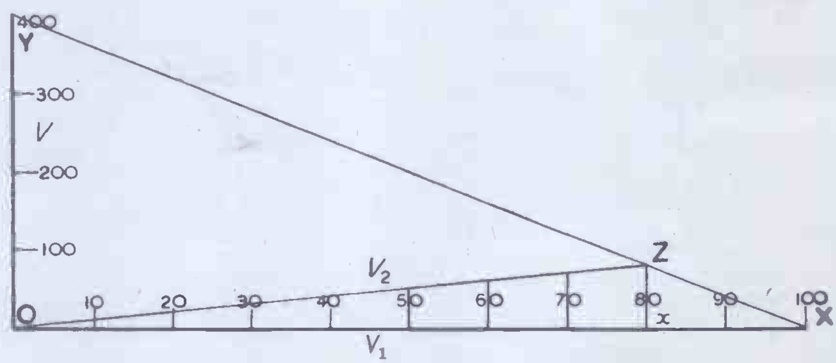
Subtracting

$$\frac{1}{V_2}-\frac{1}{V_1}=\frac{1}{V}\left\{\frac{2M+R}{M}-\frac{M+R}{M}\right\}=\frac{1}{V}$$

in other words V *(the working voltage) is the reciprocal of the difference of the reciprocals of the two voltage readings.*

A simple Abac or Alignment chart can be made which avoids the necessity for calculation.

Two lines OX, OY are drawn at right angles. OX is marked with a linear scale corresponding to that of the voltmeter. Call this V_1. OY is marked with a linear scale:—



extending to, say, four times the voltmeter range. (Call this V.)

A straight line OZ (corresponding to V_2) is marked out in the following way:—

Suppose that OX = 100 volts and OY = 400 volts,

$$\frac{1}{100}+\frac{1}{400}=\frac{5}{400}=\frac{1}{80}.$$

At $x=80$ on OX draw a perpendicular to cut XY in Z. Join OZ.

If OZ is divided into 80 parts (this can be done by drawing perpendiculars to OX through the points marked on OX) this is the scale for V_2.

If, now, V_1 and V_2 are measured as before and a straight edge is put through these points on OX and OZ, it will cut OY at the point which corresponds to V.

The "Variable Resistance" Method

In this case a variable resistance with a pointer and specially marked scale is used.

V_1 is read as above, and the resistance is increased *from zero* until the voltage reading is $V_1/2$.

If the added resistance is X

The second reading will be $VM/(M+R+X)$, and the denominator must be equal to $2(M+R)$ if the second reading is half the first.

That is $X = M+R$.

$$\text{Then } V=\left(V_1\frac{M+R}{M}\right)=V_1.\frac{X}{M}$$

If the variable resistance is provided with a scale marked in units of "meter resistance" (that is, if the meter resistance is 100,000 ohms, the point corresponding to 100,000 ohms will be marked "1" and 200,000 ohms will be marked "2," etc.), its pointer will read directly the quantity which can be called the *factor* (F).

The rule, then, is:—

Put the variable resistance at zero, note the volts (V_1), turn the pointer to halve the voltage reading, note the factor, multiply this factor by V_1. The answer is the working voltage.

NOTE:—

(1) It is, of course, unnecessary to calibrate the scale between 0 and 1.

(2) The internal resistance of the apparatus is $(F-1)M$.

(3) If a multi-range voltmeter is used, it will be necessary to mark a number of scales to correspond to the different ranges; it is not usually convenient to use the same resistance with more than two voltmeter ranges.

The Harmonic Analysis of Distorted Sine-Waves
—concluded from p. 559

By R. C. de HOLZER, D.Sc.(Tech.)

3. Wave Containing Even and Odd Harmonics

THE presence of even harmonics is manifested by a distortion of the symmetry of the waveform (*see* Part I). If the actual content of the even harmonics can be ignored, determine the algebraic mean of the absolute values of the 45°, 135°, 225° and the 315° ordinates and consider this mean value as d_1 and proceed as explained in Section 1, Part 1. The absolute values of the 0° and 180° ordinate must be equal and the deviation from zero of the 90° and the 270° ordinate should be disregarded.

If the values of the even harmonics need to be calculated a schedule must be drawn up as shown in Fig. 5. Insert the eight measured ordinates as indicated, calculate the arithmetic mean of the 45°, 135°, 225° and 315° ordinates ($= d_1$) and find the differences between this mean and the ordinates. From each pair of the latter differences, as well as from a_2 and a_6, the sum (Σ_1 Σ_2 Σ_3) and the difference (Δ_1 Δ_2 Δ_3) must be found. The further procedure is similar to the determination of the amplitudes for the curve containing odd cosine terms only (*see* paragraph 1). For two pairs of amplitudes use Table 1 given previously; for the third pair a similar Table (5). All the operations are indicated in the schedule of Fig. 5.

As example the curve of Fig. 4 is calculated:

In introducing the phase-angles of the harmonics, *i.e.*,

$$\tan \phi_n = \frac{B_n}{A_n} \quad \ldots\ldots\ldots\ldots \quad (16)$$

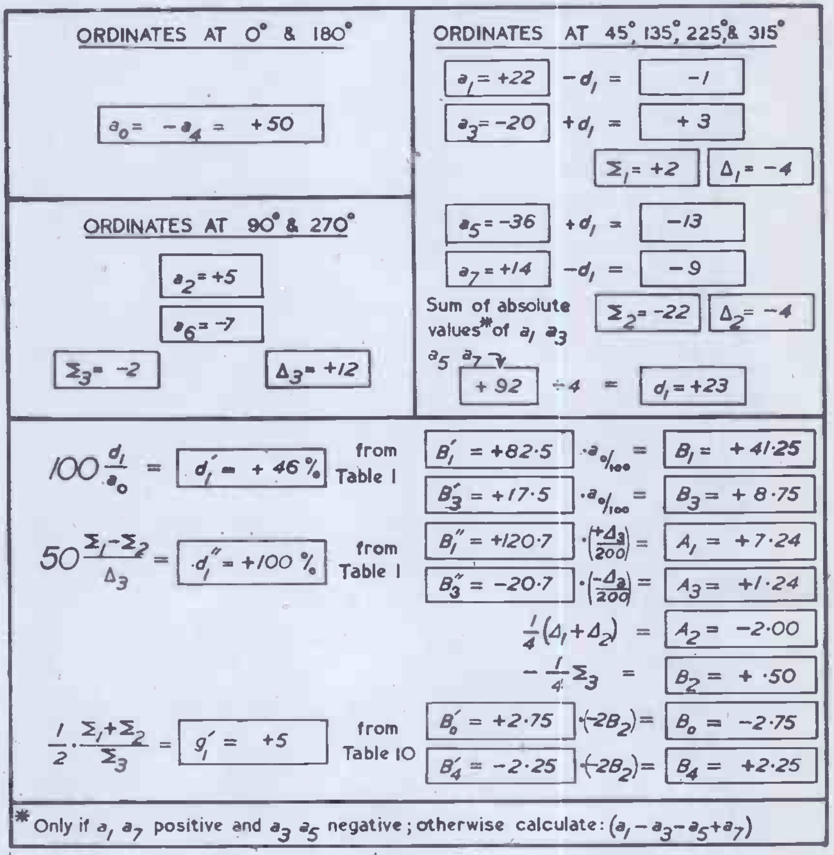
and for B_n *smaller* than A_n

$$K_n = \frac{A_n}{\cos \phi_n} \quad \ldots\ldots\ldots\ldots \quad (17)$$

for B_n *larger* than A_n

$$K_n = \frac{B_n}{\sin \phi_n} \quad \ldots\ldots\ldots\ldots \quad (18)$$

Table 4 shows this calculation for this particular example:



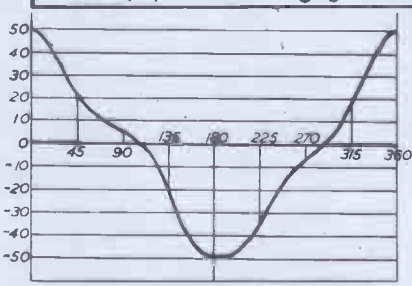


Fig. 4. Example of complex waveform analysed by the schedule (Fig. 5) given above.

Thus Fourier's series for this curve is:

$$y = -2.8 + 41.9 \cos(\alpha + 80^\circ) - 2.1 \cos(2\alpha - 14^\circ) + 8.8 \cos(3\alpha + 82^\circ) + 2.3 \cos 4\alpha.$$

TABLE 4

m	A_n	B_n	B/A	ϕ	sin ϕ	cos ϕ	K_n
1	+ 7.24	+41.25	+ 5.71	+80° 3′	.985	—	+41.87
2	− 2.0	+ .5	− .25	−14° 2′	—	.970	− 2.07
3	+ 1.24	+ 8.75	+ 7.05	+81° 56′	.990	—	+ 8.84
4	0	+ 2.25	+ ∞	+90°	1.00	—	+ 2.25

Appendix

Mathematical Deduction

(a) Curve Containing Odd Cosine Term Only

The Fourier's series is:

$$y = B_1 \cos \alpha + B_3 \cos 3\alpha$$

For $\alpha = 0°$

$$d_0 = B_1 + B_3 \quad \ldots\ldots \quad (A1)$$

For $\alpha = 45°$

$$d_1 = s(B_1 - B_3) \quad \ldots\ldots \quad (A2)$$

For $\alpha = 90°$

$$d_2 = 0$$

$$s = \cos 45° = .707$$

adding and subtracting (1) and (2)

$$B_1 = \tfrac{1}{2}\left(d_0 + \frac{d_1}{s}\right) \quad \ldots\ldots\ldots \quad (A3)$$

$$B_3 = \tfrac{1}{2}\left(d_0 - \frac{d_1}{s}\right) \quad \ldots\ldots\ldots \quad (A3')$$

in writing

$$\left.\begin{aligned} d_1/d_0 &= d_1' \\ B_1/d_0 &= B_1' \\ B_3/d_0 &= B_3' \end{aligned}\right\} \quad \ldots\ldots\ldots \quad (A4)$$

Substituting in (3)

$$B_1' = \tfrac{1}{2} + \frac{1}{2s}.d_1' \quad \ldots\ldots \text{(A5)}$$

$$B_3' = \tfrac{1}{2} - \frac{1}{2s}.d_1' \quad \ldots\ldots \text{(A6)}$$

$$\frac{1}{2s} = .707$$

These two functions of d_1' are calculated in Table 1.

(b) Separation of Component Curves

(α) *Separation of odd and even harmonics.*

Fourier's series can be written:

$a' = K_0 + K_1 \sin(\alpha + \phi_1) + K_2 \sin(2\alpha + \phi_2) + K_3 \sin(3\alpha + \phi_3) + \ldots$

The ordinate for $(\alpha + 180^\circ)$:

$a'' = K_0 - K_1 \sin(\alpha + \phi_1) + K_2 \sin(2\alpha + \phi_2) - K_3 \sin(3\alpha + \phi_3) + - \ldots$

Adding both equations:

$2e = a' + a'' = 2[K_0 + K_2 \sin(2\alpha + \phi_2) + K_4 \sin(4\alpha + \phi_4) + \ldots]$ (A7)

Subtracting both:

$2b = a' - a'' = 2[K_1 \sin(\alpha + \phi_1) + K_3 \sin(3\alpha + \phi_3) + \ldots]$ ... (A8)

Thus in *adding* each pair of ordinates of the complex curve (which have intervals of 180° between them) all the *odd* harmonic components *disappear*; in *subtracting* them, all *even* harmonic components *disappear*. (The constant term remains with the even harmonics.)

(β) *Separation of sine- and cosine-terms of odd harmonics.*

Fourier's series for a wave containing only odd harmonics is:

$b' = A_1 \sin \alpha + A_3 \sin 3\alpha + \ldots + B_1 \cos \alpha + B_3 \cos 3\alpha + \ldots$

The ordinate for the supplementary angle $(180 - \alpha)$ is:

$b'' = A_1 \sin \alpha + A_3 \sin 3\alpha + \ldots - B_1 \cos \alpha - B_3 \cos 3\alpha - \ldots$

Adding both equations:

$2c = b' + b'' = 2[A_1 \sin \alpha + A_3 \sin 3\alpha + \ldots]$ .... (A9)

Subtracting both:

$2d = b' - b'' = 2[B_1 \cos \alpha + B_3 \cos 3\alpha + \ldots]$ .... (A10)

Thus in *adding* all supplementary ordinates of a complex curve containing only odd harmonics the *cosine-terms* disappear; in *subtracting* them, the *sine-terms* disappear.

(γ) *Separation of sine- and cosine-terms of even harmonics.*

Fourier's series for a wave containing only even harmonics is:

$e' = A_2 \sin 2\alpha + A_4 \sin 4\alpha + \ldots + B_0 + B_2 \cos 2\alpha + B_4 \cos 4\alpha + \ldots$

TABLE 5

for g'_1 positive read downwards					
g'_1	B'_0	B'_4	g'_1	B'_0	B'_4
0.0	+ .25	+ .25	6.0	+ 3.25	− 2.75
.2	.35	+ .15	.5	3.50	3.0
.4	.45	+ .05	7.0	3.75	3.25
.6	.55	− .05	.5	+ 4.0	− 3.50
.8	.65	− .15	8.0	4.25	3.75
1.0	+ .75	− .25	.5	4.50	4.0
.2	.85	− .35	9.0	4.75	4.25
.4	.95	− .45	.5	5.0	4.50
.6	1.05	− .55	10.0	+ 5.25	− 4.75
.8	1.15	− .65	.5	5.50	5.0
2.0	+ 1.25	− .75	11.0	5.75	5.25
.2	1.35	− .85	.5	6.0	5.50
.4	1.45	− .95	12.0	6.25	5.75
.6	1.55	− 1.05	.5	+ 6.50	− 6.0
.8	1.65	− 1.15	13.0	6.75	6.25
3.0	+ 1.75	− 1.25	.5	7.0	6.50
.5	2.0	− 1.50	14.0	7.25	6.75
4.0	2.25	− 1.75	.5	7.50	7.0
.5	2.50	− 2.0	15.0	+ 7.75	− 7.25
5.0	+ 2.75	− 2.25	.5	8.0	7.50
.5	3.0	− 2.50	16.0	8.25	7.75
6.0	+ 3.25	− 2.75	.5	+ 8.50	− 8.0
g'_1	B'_4	B'_0	g'_1	B'_4	B'_0
for g'_1 negative read upwards					

Table Values: $B'_0 = .25 + .5\, g'_1$ $\quad B'_2 = .50$
$B'_4 = .25 + .5\, g'_1$ $\quad B'_0 + B'_2 + B'_4 = 1$

The ordinate for the supplementary angle $(180 - \alpha)$ is:

$e'' = -A_2 \sin 2\alpha - A_4 \sin 4\alpha - \ldots + B_0 + B_2 \cos 2\alpha + B_4 \cos 4\alpha + \ldots$

Adding both equations:

$2g = e' + e'' = 2[B_0 + B_2 \cos 2\alpha + B_4 \cos 4\alpha + \ldots]$ (A11)

Subtracting both:

$2f = e' - e'' = 2[A_2 \sin 2\alpha + A_4 \sin 4\alpha + \ldots]$ (A12)

Thus, in *adding* all supplementary ordinates of a complex curve containing only even harmonics, the *sine-terms* disappear; in *subtracting* them, the *cosine-terms* disappear.

(δ) *Separation into components of 45° ordinates.*

The complex curve is given by

the 0° ordinate ...... a_0
,, 45° ,, ... a_1
etc.
,, 315° ,, ... a_7

This measurement is to be made from an x-axis so laid that

$a_0 = -a_4$ .... (A14)

The ordinates of the component curve containing only *odd* harmonics are from (8) and (13):

$2b_0 = a_0 - a_4 = 2a_0$
$2b_1 = a_1 - a_5$
$2b_2 = a_2 - a_6$
$2b_3 = a_3 - a_7$

and those containing the *even* harmonics, from (7) and (13):

$2e_0 = a_0 + a_4 = 0$
$2e_1 = a_1 + a_5$
$2e_2 = a_2 + a_6$
$2e_3 = a_3 + a_7$

The component curve of the odd sine-terms, from (9):

$c_0 = 0$
$2c_1 = b_1 + b_3$
$c_2 = b_2$

and those of the odd cosine-terms, from (10):

$d_0 = b_0$
$2d_1 = b_1 - b_3$
$d_2 = 0$

The component curve of the even sine-terms, from (12):

$f_0 = 0$
$2f_1 = e_1 - e_3$
$f_2 = 0$

and those of the even cosine-terms, from (11):

$g_0 = e_0 = 0$
$2g_1 = e_1 + e_3$
$g_2 = e_2$

Substituting the original ordinates as given above:

$$c_1 = \tfrac{1}{4}[(a_1 + a_3) - (a_5 + a_7)] \quad \text{(A14)}$$
$$c_2 = \tfrac{1}{2}(a_2 - a_6) \quad \text{(A15)}$$
$$d_0 = a_0 \quad \text{(A16)}$$
$$d_1 = \tfrac{1}{4}[(a_1 - a_3) - (a_5 - a_7)] \quad \text{(A17)}$$
$$f_1 = \tfrac{1}{4}[(a_1 - a_3) + (a_5 - a_7)] \quad \text{(A18)}$$
$$g_1 = \tfrac{1}{4}[(a_1 + a_3) + (a_5 + a_7)] \quad \text{(A19)}$$
$$g_2 = \tfrac{1}{2}(a_2 + a_6) \quad \text{(A20)}$$

(c) Schedule for the Calculation of Odd and Even Harmonics

(α) *The odd cosine-terms.*

d_1' is obtained from (4), (16), and (17) from which in Table 1 the values of B_1' and B_3' may be read [Table 1 is calculated from (5) and (6)].

(β) *The odd sine-terms.*

The Fourier's series for this particular case is obtained from that for odd cosine-terms by reversing the sequence of the ordinates and changing the algebraic sign of B_3.

The same Table 1 may be used if for (4) is written:

$$d_1'' = 100\, c_1/c_2 \quad \text{(A21)}$$

c_1 and c_2 are found from (14) and (15) and in Table 1 the values of B_1'' and B_3''. The amplitudes are:

$$\left.\begin{array}{l} A_1' = B_1'' \\ A_3' = -B_3'' \end{array}\right\} \quad \text{(A22)}$$

(γ) *The even sine-terms.*

Fourier's series for the 45° ordinates is:

$$f_1 = A_2 \sin 90° + A_4 \sin 180°$$

or

$$A_2 = f_1 \quad \text{(A23)}$$

f_1 is found from (18).

(δ) *The even cosine-terms.*

Fourier's series for the 0°, 45° and 90° ordinates, if the real values of the trigonometric functions are introduced, are:

$g_0 = B_0 + B_2 + B_4$
$g_1 = B_0 - B_4$
$g_2 = B_0 - B_2 + B_4$

The amplitudes become:

$$B_0 = \tfrac{1}{4}(g_0 + 2g_1 + g_2) \quad \text{(A24)}$$
$$B_2 = \tfrac{1}{2}(g_0 - g_2) \quad \text{(A25)}$$
$$B_4 = \tfrac{1}{4}(g_0 - 2g_1 + g_2) \quad \text{(A26)}$$

It has been shown above that

$$g_0 = 0 \quad \text{(A27)}$$

Writing

$$\left.\begin{array}{l} g_1' = g_1/g_2 \\ B_0' = B_0/g_2 \\ B_4' = B_4/g_2 \end{array}\right\} \quad \text{(A28)}$$

and substituting (27) and (28) in (24) to (26),

$$B_0' = .25 + .5g_1' \quad \text{(A29)}$$
$$B_2 = -\tfrac{1}{2}g_2 \quad \text{(A30)}$$
$$B_4' = .25 - .5g_1' \quad \text{(A31)}$$

g_2 is found from (20),

g_1' from (19), (20), and (28). Insert this value in Table 10 which is calculated from (29) and (31) and read the values of B_0' and B_4'.

To obtain the real amplitudes the latter has to be multiplied by g_2 or by $(-2B_2)$.

ELECTRONIC STIMULATORS (*Contd. from p. 588*)

Description

The following controls are provided (Fig. 4):

1. Push-button selector panel. When any of the buttons grouped under "stimulation" or "iontophoresis" is pressed, the instrument is switched on to that mode of operation. It is switched off by pressing the central "mains off" button.

2. The central dial is the voltage output control and is calibrated in volts up to 100. When the low voltage "10 V." button is pressed, the output voltage is one-tenth of that shown on the dial. The neon pilot light is incorporated with the hairline.

3. The lower left-hand knob controls the frequency or pulse repetition rate which can be set to 1.5, 5, 10, 50, 70, 100 or 1,000 cycles per second (c/s.).

4. The lower right-hand knob controls pulse duration, which can be set to 0.02, 0.05, 0.1, 0.5, 1.0, 10 or 100 msec.

At the top centre is the D.C. output meter calibrated from 0 to 5 mA. This range is correct when the "iontophoresis 0-5 mA" button is pressed. When the 0-50 mA button is pressed the output is ten times that shown on the meter.

Looking at the back, the socket for the output leads is at the right. The cathode and anode are marked, the cathode being on the left. The anode is connected to the case, and is therefore "earthy." The socket is keyed so that the leads plug cannot be inserted incorrectly.

On the top of the case is a waterproof tray under the lid. This is for storage of leads and electrodes.

Adjustment for various mains voltages is provided on an engraved connecting block mounted on the underside of the chassis. The two flexible leads must be inserted in the appropriate sockets labelled with the voltage of the mains supply available—110 to 250 V. Alternating current only can be used, at a frequency from 40 to 60 c/s.

Behind the front panel is fixed a telephone earpiece which is permanently connected across the output circuit. This gives an audible click for each stimulus so that the operator can judge when to expect a response.

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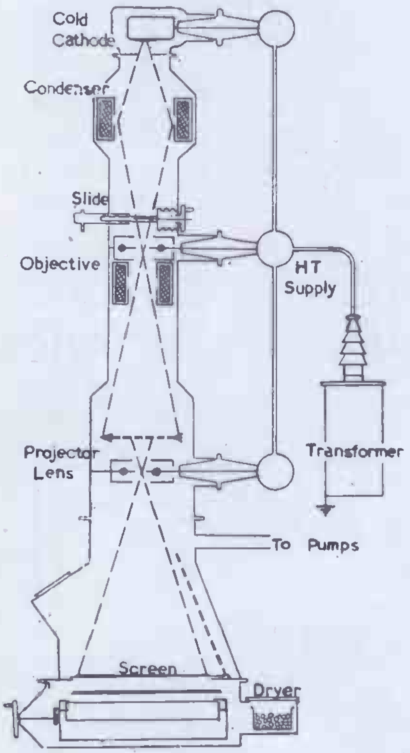
A New Swiss Electron Microscope

Various electron microscopes which have been constructed up to now have used either electrostatic or electromagnetic focusing exclusively. It is considered by Swiss engineers that a combination of electrostatic and electromagnetic lenses should avoid the aberrations usually associated with magnetic focusing, and the results of their experimental work are found in the Trüb-Täuber Electron Microscope.



As the diagram shows, a cold cathode is used in conjunction with two electrostatic lenses supplied with 50 kV from an oil-immersed transformer. An electromagnetic lens is used for focusing on to the object, the stage being specially constructed for fine adjustment of the object. It is claimed that an accuracy of setting of 1/10,000 mm. can be obtained.

The objective is a composite lens system, the electrostatic lens providing a fixed degree of refraction and the magnetic lens giving a fine adjustment of focus. Another electrostatic lens acts as the projector. The photographic arrangements are according to the usual practice.

—*F. Neurath.*

Balanced Amplifier Circuits

It is often necessary to feed unbalanced signals to an amplifier feeding a balanced output circuit. For example, in the case of a saw-tooth generator driving a balanced amplifier feeding the deflecting plates of a cathode-ray tube, it is important to ensure that the scanning potentials applied to the plates vary equally and oppositely. For this reason, the valves of the amplifier are often provided with a common cathode resistance of high value, and the driving signal is applied to the control grid of one valve, while the control grid of the other valve is held at a fixed potential. This gives the desired balanced output, but requires a comparatively high anode voltage supply due to the large voltage drop across the cathode resistance.

An alternative method avoiding this disadvantage of the high cathode resistance is to drive one valve of the amplifier directly and to develop the drive for the other valve by feeding a fraction of the output of the first valve to the control grid of the second valve. This arrangement is, however, susceptible to changes in supply voltages and valve characteristics, but by the introduction of negative feedback it can be rendered very stable.

A typical circuit is shown in the drawing. Valve V_1 has the scanning signal applied to its control electrode and develops a saw-tooth output across resistance R_1, one deflecting plate P_1 of a cathode-ray tube T receiving this output from the anode of V_1. Valve V_2 is driven by a fraction of the output voltage derived from the anode of V_1 via resistances R_3 and R_4 and its output voltage developed across resistance R_2 and fed to deflecting plate P_2 of the tube T. To maintain balance, a further resistance R_5 is connected between the anode and control grid of V_2, so intro-

(*Continued in next column.*)

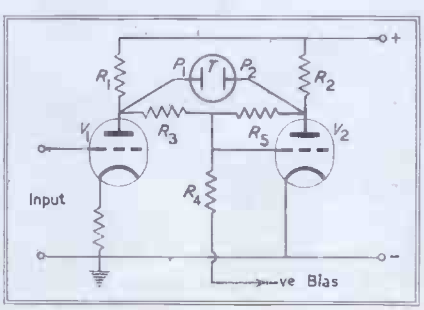


Photo-Mechanical Oscillators

Addendum

Owing to an oversight, the figure referred to in the letter from Baldock and Grey Walter in the last issue was omitted from the text. This record is to demonstrate that in the instrument developed by them (referred to in the correspondence on this subject) an important feature is that the several components of a complex waveform can be displayed separately at the same time as the resultant.

In the figure the top tracing shows the synthesis of the "wave and spike" formation diagnostic of minor epilepsy. This waveform is built up from 10 sine components, of which the fundamental is much the largest and forms the wave. In the second channel the fundamental is omitted, leaving only the harmonic components responsible for the spike. Further channels are used in practice to display the separate components in their respective amplitudes.

Balanced Amplifier Circuits (*contd.*)

ducing negative feedback which tends to prevent any change of the amplitude of the anode voltage of V_2 from equality with the amplitude of the anode voltage of V_1. By suitable choice of the values of R_3, R_4 and R_5 the swings on the anodes of V_1 and V_2 can be made equal and opposite.

As shown in the drawing, the feedback coupling passes both A.C. and D.C. so that in addition to ensuring balance of the A.C. amplitudes the mean potentials of the plates will also be stabilised. If this A.C. stabilisation is not required, it is only necessary to introduce a series capacity into the feedback path. On the other hand, should the D.C. stabilisation be required without the A.C. stabilisation, the feedback circuit must be arranged to pass D.C. and not A.C., as, for example, by including series inductance.

—*Communicated by E.M.I. Laboratories.*

ABSTRACTS OF ELECTRONIC LITERATURE

CIRCUITS

The Circuit Design of Intermediate Frequency Amplifiers
(C. P. Beanland and G. L. Grisdale)

This article summarises the considerations and methods applied in the design of an intermediate frequency amplifier for a receiver; it presents the salient features of practical design, already available, though not in such compact form, in various papers and books.

—*Marconi Review*, No. 77, April-June, 1945.

Electronic Alternating-Current Power Regulator
(L. B. Cherry and R. F. Wild)

An electronic A.C. power regulator is described which is instantaneous and independent of frequency. The theory and design considerations governing a conventional circuit using gaseous discharge tubes are presented. The effect of the extent of voltage limiting by the gas tubes on the degree of regulation is discussed. A bridge-type circuit is described and its theory developed and the effect of the degree of unbalance of the bridge circuit on the degree of regulation considered. The application of these circuits for regulation of low power, particularly when used in electronic apparatus, is studied and performance data on both circuits are given.

—*Proc. I.R.E.*, April, 1945, p. 262.*

Frequency Meter for Use with Geiger-Müller Counter
(L. F. Curtiss and B. W. Brown)

An improved circuit is described for reading the rate of pulses from a Geiger-Müller counter. Based on the usual procedure of levelling and rectifying the pulses to charge a condenser, the improvements concern a bridge-type vacuum-tube voltmeter to read the voltage on the condenser and an arrangement to compensate parasitic potentials developed in the rectifier for the pulses. An adequate source of potentials from one small transformer is described, which renders the circuit useful in portable instruments. Particular care has been taken to design a circuit that is independent of the voltage of the A.C. mains.

—*J. Res. Nat. Bur. Std.*, January, 1945, p. 53.*

ELECTRON OPTICS

Additional Stabilisation for the Beam Current in the R.C.A. Type B Electron Microscope
(H. R. Crane)

A circuit which gives additional stabilisation of the electron beam in the R.C.A. Type B electron microscope is described. By means of a one-tube circuit the fluctuations in filament emission are reduced by a factor of at least ten. In this way the fuzziness of the photograph produced by beam fluctuations and the unsymmetrically charged wax coating on the aperture diaphragms is reduced.

—*Rev. Sci. Inst.*, March, 1945, p. 58.

A 100-kV Electron Microscope
(L. Marton)

A transmission-type of electron microscope with magnetic lenses is described. The electron speed can be varied between 30 ekV and 100 ekV. Magnification is produced in three stages and the instrument has improved air locks, hydraulically operated stage movement and a stage-tilting device up to $\pm 15\frac{1}{2}^{\circ}$. It is also provided with means for bright and dark field illumination and for conversion into a diffraction camera. Improved electrical circuits provide the necessary stability of the power supplies.

—*J. App. Phys.*, March, 1945, p. 131.*

INDUSTRY

An A.C.-Operated Leak Detector and Ionisation Gauge
(R. B. Nelson)

Small leaks in vacuum systems may be found by observing the change in temperature-limited thermionic emission of a tungsten filament in the vacuum as oxygen is blown over the leak. An apparatus is described for regulating the filament heating power so that the emission is not affected by line voltage fluctuations. The apparatus also operates as an ionisation gauge with emission control.

—*Rev. Sci. Inst.*, Vol. 16 (March, 1945), p. 55.

* Abstracts supplied by the courtesy of Metropolitan Vickers Electrical Co. Ltd., Trafford Park, Manchester

BOOK REVIEWS

Television for Everyman
A Non-Technical Exposition

F. W. Kellaway. (John Crowther. 5s. net.) 55 pp.

I am Everyman, or, to be more precise, Everywoman, and after reading this book three times (a feat requiring a great deal of willpower) I find there is much I still do not understand. In fact, so far from increasing my interest in the subject, Mr. Kellaway has effectively stifled it at birth. (Lest he point out that his book is for "the intelligent amateur," let me hasten to say, without undue modesty, that school and university have done their best for me, and if intelligence tests are anything to go by, I may consider myself in the top 7 per cent. of the population in that respect.)

The truth is, of course, that this book was not written for Everyman at all, that term generally implying the man in the street, but for those of the men in the street who have more than a nodding acquaintance with physics, mathematics and the science of wireless telegraphy. The author does suggest that the first chapter, on the physics involved, may be omitted if desired and hints that it is not essential to follow the mathematical calculations, but, while finding the first chapter more interesting and instructive than any other, Everyman would have been spared much exasperation if Mr. Kellaway had categorically stated his mathematical conclusion as, in fact, he stated his original equations (p. 25).

I cannot help feeling that the author has been more concerned with keeping his title in line with that of his previous book, "Wireless for Everyman," than with explaining the science of television in a form intelligible to the public for whom he ostensibly writes.

M. M. CAIRD.

Sound Film Projection

F. W. Campbell, T. A. Law, L. F. Morris, A. T. Sinclair. (Geo. Newnes, Ltd. 18s. net.) 225 pp. fully illustrated.

This book has been written by four engineers from the well-known sound projection firms—B.T.-H., British Acoustic Films, Western Electric, and R.C.A. Photophone, under the editorship of E. Molloy.

After a preliminary description of the principles of sound recording and reproduction, four widely used systems of sound projection are dealt with in detail by the specialist in each system.

Succeeding chapters give particulars of portable equipment, installation and maintenance, and fault tracing. The installation of sound reinforcing equipment in theatres is also mentioned.

The book is obviously an authoritative account which should be of great value to the projectionist and to students taking up projection work. The explanations are clear and well illustrated by photographs and line drawings and the book is one to be recommended.

CLASSIFIED ANNOUNCEMENTS.

The charge for miscellaneous advertisements on this page is 12 words or less 4/- and 4d. for every additional word. Box numbers count as four words, plus 1/- extra for replies. Remittance should accompany advertisement. Cheques and P.O.'s payable to Hulton Press Ltd., 43 Shoe Lane, E.C.4. Press date—15th month for following issue.

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PRECISION OPTICAL SYSTEM, producing knife-edge line of light from any car headlight bulb, for scanning sound track of film direct into photo cell, brass tube 2 in. long, ⅝ in. dia., ½ in. focus, 52/-; full instructions free, goods by return. CEFA INSTRUMENTS, 38a, York Street, Twickenham, Middlesex. Phone: POPesgrove 6597.

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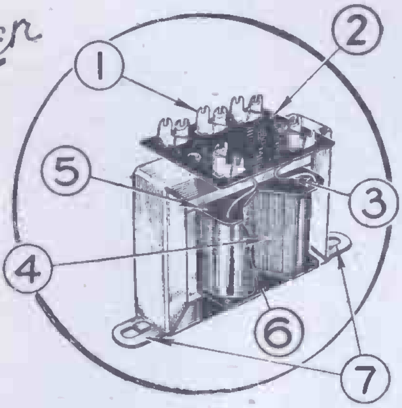

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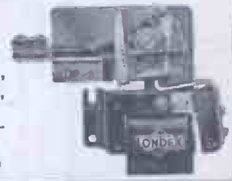

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