Equipment for Acoustic Measurements

(Part 3)

Acoustic Pulse Measurements

By

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IN 1945, when acoustic research was recommenced by the B.B.C., it was decided to investigate the use of pulses for determining the acoustic properties of studios as an adjunct to normal reverberation methods. Mason and Moir[1] had already used pulses and their results showed sufficient promise to make further investigation worthwhile. At first some standard apparatus was modified and used for the initial laboratory experiments, but it soon became evident that special lightweight equipment would have to be developed for field use. The original apparatus consisted of five units, a triggered time-base, an oscilloscope, a tone pulser, a microphone amplifier and a mains unit, having a total weight of 160lb. In the new design these units were reduced to two, a tone pulser and a triggered time-base oscilloscope, with a total weight of less than 42lb.

Fig. 1 is a block schematic diagram of the complete equipment and Fig. 2 is a photograph of the units ready for use. In operation a pulse of tone is radiated into the studio under test by means of a loudspeaker and the sound in the studio is picked up by a microphone, which is connected to the amplifier incorporated in the oscilloscope, and hence to the Y plates of the cathode-ray tube. The time-base is triggered concurrently with the start or end of the tone pulse and makes one complete sweep at a speed which is adjustable within wide limits. The build-up or decay of sound in the studio can thus be observed on an appropriate time scale for tone pulses of any frequency or duration.

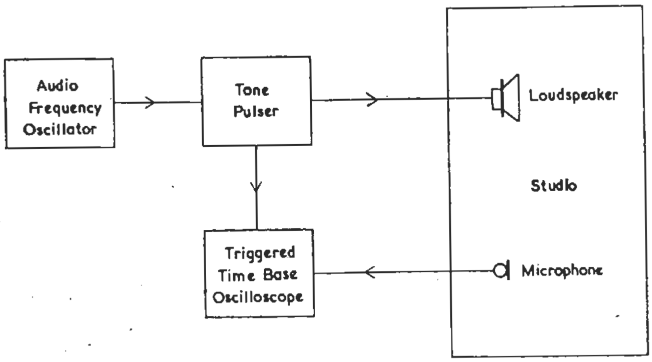

Fig. 1. Block schematic diagram of experimental chain

The tone pulser has a triggering circuit which initiates the tone pulse and also the time-base of the oscilloscope. The circuit is so arranged that it will generate either single pulses of tone or repeated pulses at a repetition rate which can be varied to suit the size of the studio.

Considerable use has been made of well-known techniques in radar timing and pulse circuits. The fact that the time scale is in seconds rather than microseconds has made most problems easier but, in a few instances, special modifications have been required.

The Triggered Time-Base Oscilloscope

The triggered time base oscilloscope contains a 3in. cathode ray tube and a time-base which may be set for either single triggered strokes or self-running as required. In addition there is a Y plate amplifier with sufficient gain to raise signals from microphone level for application to the Y plates. The unit complete with power supplies weighs just under 30lb, and the layout has been designed to give good accessibility to all components, while keeping the dimensions of the carrying case (7in. by 15in. by 12in. high) as small as possible. B7G based valves are used throughout with the exception of the first stage of the Y plate amplifier and the low voltage H.T. rectifier, and holders are provided to carry a spare for each type of valve. Fig. 3 is a circuit diagram of the oscilloscope.

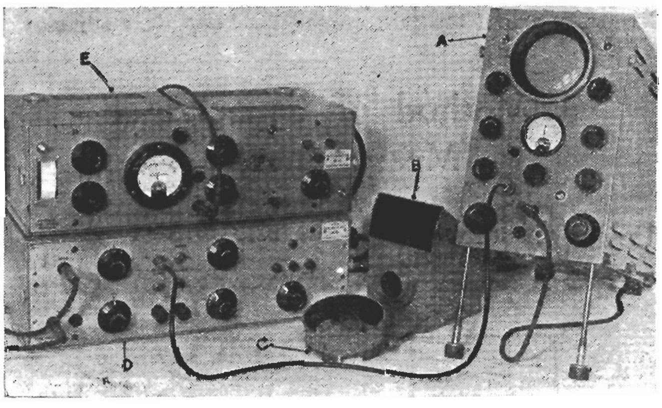

Fig. 2. Equipment for acoustic pulse measurements
(a) Triggered time-base oscilloscope. (b) Camera attachment. (c) Graticule. (d) Tone pulser. (e) Audio frequency oscillator.

The Time-base and Flyback Suppression Circuit V_1 to V_7

The time base circuit is preceded by a delay circuit consisting of V_1 and V_2 which can delay the initiation of the time-base by an interval continuously variable from 1-250 milliseconds. This delay can be used as necessary by throwing the switch S_1 which normally allows the triggering pulse to by-pass the delay circuits.

Both the delay and time-base circuits are based on the Miller integrator[2,3] principle, which may be described with reference to the simplified circuit of Fig. 4.

Before the arrival of the initial triggering pulse the circuit is in a state of equilibrium with the control grid acting as a diode and drawing current from the H.T. line

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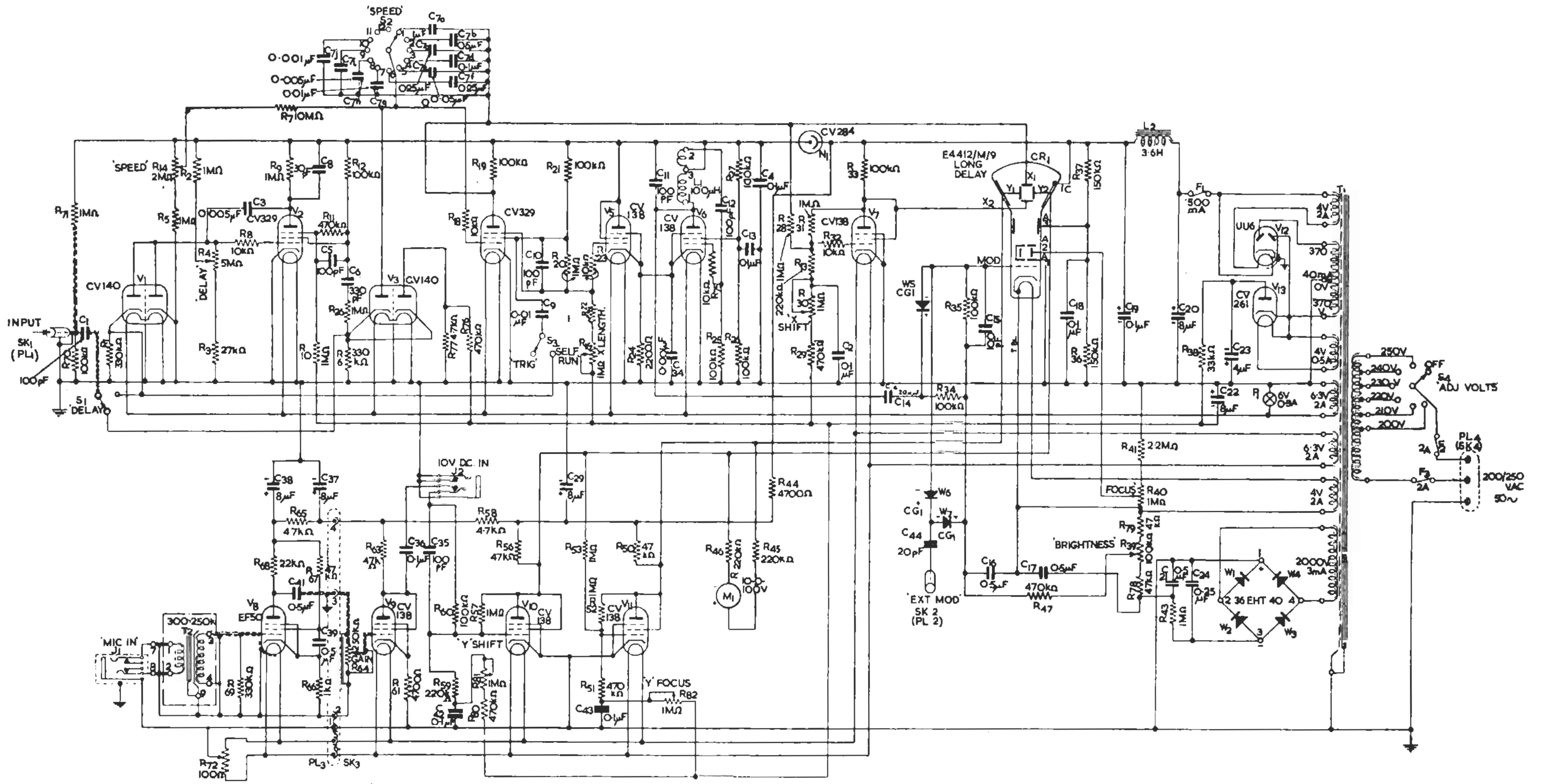


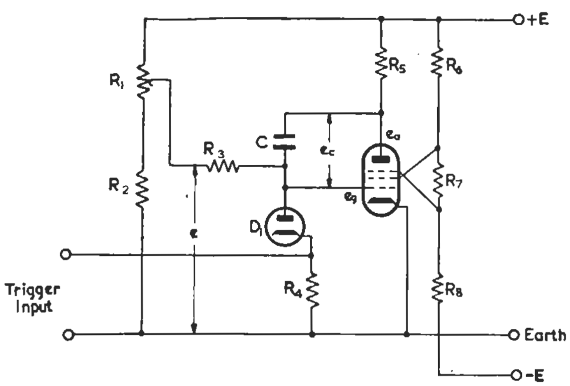
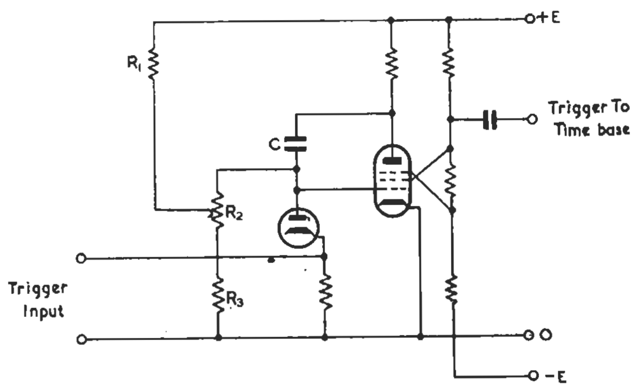


Fig. 3 (above). Circuit of the time-base oscilloscope

Fig. 4 (left). Basic Miller time-base

Fig. 6 (right). Basic relay circuits



via R_1 and the high resistance R_3. The control grid being thus at earth potential, the valve draws a heavy space current and if it is assumed that the whole of this space current flows from the screen, the voltage drop across the screen resistance R_6 is high and the screen potential is correspondingly low. The values of R_7 and R_8 are so chosen that the suppressor grid is now at a sufficiently negative potential with respect to the cathode to cut off the anode current completely and the circuit is thus in a stable condition with the anode potential held at the full H.T. voltage E and the capacitor C charged to a potential of E volts.

The trigger voltage is a negative pulse, introduced at the cathode of the diode D_1, which drives the grid momentarily negative and the valve space current is thus cut off, causing the potential of the screen and suppressor grids to rise sharply. The suppressor grid is now at a sufficiently high potential to allow anode current to flow, causing a drop of anode potential which, by means of the charged capacitor C, carries the grid negative. The anode current is thus arrested and the anode potential can only drop as C discharges into the anode.

A state of equilibrium is then set up in which the anode

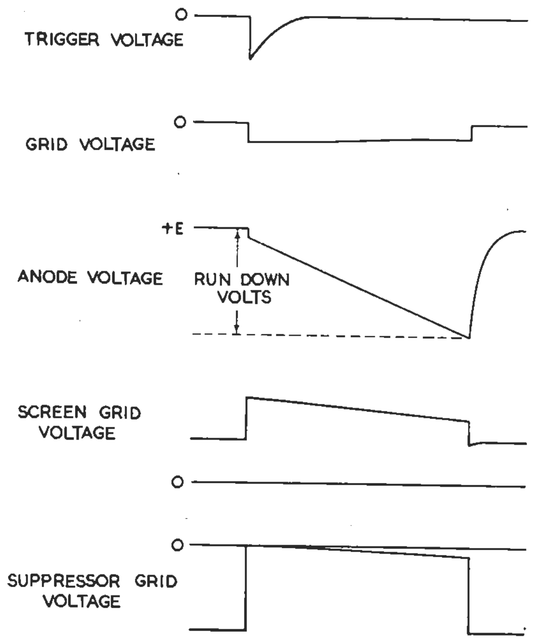


Fig. 5. Time-base waveforms

potential decreases as C discharges and this decrease of anode voltage is linear with time as may be shown as follows.

Let I be the current flowing to discharge C and e_c the voltage across the capacitor C. Then:

$$I = C \; de_c/dt$$

Since the control grid is almost at earth potential the current I will flow from the H.T. line (at potential E) via R_3. Also e_c will be equal to e_a the anode voltage, to a first approximation:

$$I = E/R_3 = C \; de_a/dt$$

$$\text{and } de_a/dt = E/R_3C$$

The rate of change of anode voltage is thus seen to be linear with time.

When the anode potential is falling the anode current must be rising and this rise will be accompanied by an increase of potential on the control grid. This will cause the "run-down" to deviate from a linear law, since the grid voltage will not remain at earth potential and the current I will therefore vary during the cycle.

If μ is the gain of the valve and E_T is the change of anode volts the voltage change on the grid will be approximately:

$$e_g = E_T/\mu$$

During the cycle the current will thus vary by an amount:

$$\delta I = E_T/\mu R_3$$

If the gain of the valve is of the order of 100, a figure easily obtainable in practice, $E \gg E_T/\mu$ and the current will remain constant, giving a linear "run-down".

The decrease of anode volts continues until the anode "bottoms". The capacitor C continues to discharge into the anode and the grid potential therefore rises sharply, causing a rise of screen current which drops the screen potential and with it the suppressor grid potential. The drop in suppressor grid potential is sufficient to cut off the anode current. The capacitor C then recharges through the anode load R_5 and the diode action of the control grid, thus resetting the circuit in its initial condition for the next triggering pulse.

The potentials on the various electrodes during the cycle are shown in Fig. 5.

The methods employed for speed control on the time base are to switch the capacitor C for coarse control and, for the fine control, to vary the potential e which provides the charging current of the capacitor. A reduction of e increases the "run-down" time of the anode, but as e becomes comparable with the voltage changes on the grid, the action is no longer linear and in view of this the values of R_1 and R_2 are so chosen that the potential e varies in the ratio 3:1. This gives a good overlap between the various capacitances and provides adequate "fine" control.

The method of obtaining variable delay is shown in Fig. 6. In this circuit non-linearity of the rate of change of anode volts is unimportant as we are interested only in the time taken, hence a substantial reduction of the potential e is permissible. The action is as follows:—

The resistance R_2 is five times the resistance R_1, and R_3 is about 1/50 of R_1. The minimum delay is obtained with the slider of R_2 at the grid end of the potentiometer in which position the "run-down" time is proportional to

$$R_1/E$$

The maximum delay is obtained with the slider at the bottom end of R_2 where the potential available is

$$\frac{E\,R_3}{R_1 + R_3} \approx E/50$$

The series resistance is $R_2 = 5R_1$ and the "run-down" time is thus proportional to

$$\frac{E/50}{5R_1} = \frac{250R_1}{E}$$

The delay time may thus be varied approximately in the ratio 250:1.

The square wave form of the screen grid is used after differentiation to deliver a triggering pulse in both the delay and time base circuits. In the delay valve the pulse is used to trigger the time-base, and in the time-base the pulse triggers the delay valve via the switch S_3 (Fig. 3) when a self-running time-base is required.

The "Miller run-down" of the time base valve thus provides a linear sweep for the cathode-ray tube; one of the X plates is driven direct from the time-base valve and the other via the directly coupled phase reversing valve V_7, so that a push-pull drive is provided and trapezoidal distortion obviated. The time-base is continuously variable between 5 milliseconds and 15 seconds by means of the coarse and fine controls. The length of sweep is adjustable by R_{16} which determines the end of the "run down" before the time-base valve resets and R_{30} varies the grid potential and hence the anode potential of V_7, thereby giving an X shift.

Flyback Suppression

The suppressor grid of the time-base valve V_4 provides a suitable wave form for the suppression of the flyback by application of a negative potential to the grid of the cathode-ray tube. The grid of the cathode-ray tube is at a high negative potential with respect to earth and consequently a capacitor must be interposed. The sweep times used in the instrument are so long that an inconveniently large capacitor would be required, and to overcome this difficulty the flyback suppression pulse is converted to radio frequency. The circuit associated with V_6 forms a 1Mc/s oscillator which is switched on and off by the suppressor grid of the time-base valve via V_5. The radio frequency pulses so formed are transmitted through the high-voltage working capacitor C_{14} and are converted to a negative voltage for suppression of the flyback by the rectifier W_5. The provision of rectifiers W_6 and W_7 permits grid modulation from an external source.

The Y Plate Amplifier

The Y plate amplifier V_8 to V_{11} has sufficient gain to raise signals from microphone level for direct application to the deflexion plates of the cathode-ray tube.

A high step-up input transformer is used so that the signal at the grid of V_8 is sufficiently great to enable A.C. to be used on the heater supply to this valve. Some cathode feedback prevents overloading of the input stage at high sound levels. The second stage also employs cathode feedback, but here a gain control R_{64} is provided on the grid. V_{10} and V_{11} form a direct coupled paraphase pair and provide a balanced push-pull drive for the Y plates of the cathode-ray tube.

As the focus of the tube is dependent upon the mean potential of the Y plates, a control R_{82}, in conjunction with the Y shift control R_{81}, has been provided to adjust the mean potential for best average focus over the face of the tube.

The meter M_1, calibrated in volts, indicates the potential difference between the Y plates, and may therefore be used for calibrating the Y deflexion.

The Cathode-ray Tube and Power Supplies

Since many of the phenomena in acoustics may take seconds to elapse, the time-base speeds are very slow and a cathode-ray tube with a long after-glow screen is used to obtain oscillograms for immediate observation. When a permanent record is required a camera attachment is used for taking either single photographs or repeated traces by moving the film at constant speed.

The low voltage rectifier, a UU6, provides 370 volts for the time-base circuits and microphone amplifier, while the negative potentials required for the bias of the time base, delay, and D.C. amplifier valves are derived from a miniature half-wave rectifier with *RC* smoothing. A neon voltage regulator N_1 is placed in series with the H.T. supply to the time base circuits as a protection for the capacitors against voltage surges.

The E.H.T. supply for the cathode-ray tube is derived from a bridge rectifier and conventional *RC* smoothing is used.

The Tone Pulser

The tone pulser receives tone from an external audio-frequency oscillator and by means of a stabilized electronic switch converts it into pulses of accurately known length. The instrument is completely self-contained and is enclosed in an aluminium carrying case measuring 17in. by 6in. by 10in. high. Its weight is 12lb.

The circuit of this instrument is shown in Fig. 7. V_3, V_4, N_1 and N_2 constitute the stabilized electronic switch which is operated either by a push button for a single pulse or, if repeated pulses are required, by a transitron oscillator V_2. V_5 and V_6 form a push-pull audio-amplifier which is switched on and off by the electronic switch.

The Push Button Trigger and Transitron Oscillator

The push button trigger circuit, consisting of R_{11} R_{12} C_6 C_{19} and one of the diodes of V_3, provides a single negative pulse to start the electronic switch and the time-base of the triggered time-base oscilloscope. Prior to operation of the push button S_5 the capacitor C_6 will be charged up to a voltage determined by R_{11} and R_{12}. When S_5 is closed the voltage across R_{11} is reduced to zero and the charge on C_6 is applied directly

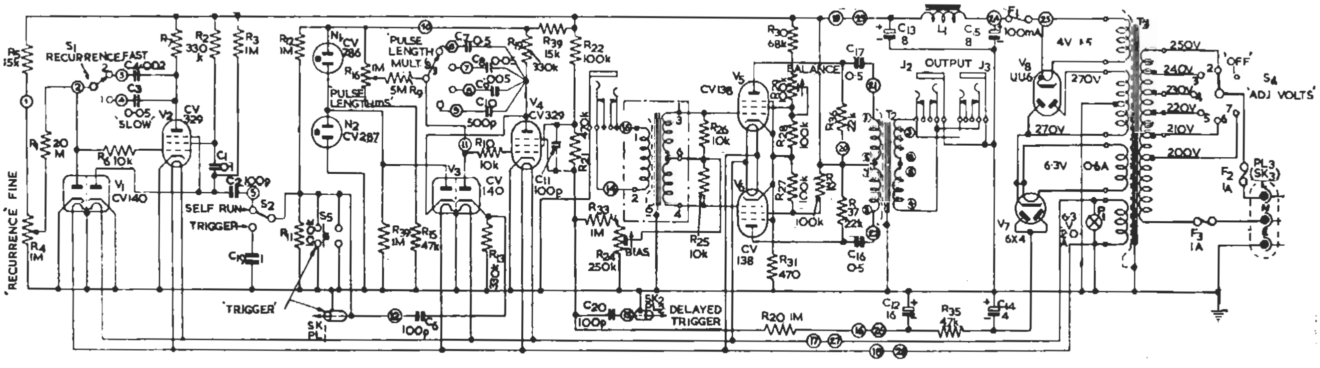


Fig. 7. Circuit of the tone pulser

across R_{13} in such a manner that the cathode of the diode is negative with respect to earth. C_6 is small and discharges rapidly through R_{13} resulting in a sharp negative pulse at the cathode of the diode.

When the push button is released, C_{19} prevents the voltage across R_{11} from rising rapidly and giving a positive pulse across R_{13}. The diode removes all positive excursions of voltage and a single negative pulse appears at the grid of the electronic switch.

The transitron oscillator is used to provide an automatic negative triggering pulse at any predetermined interval between 0.5 and 30 seconds. It consists of V_1 and V_2 and their associated components. The circuit is based on the Miller integrator principle already described, but is made self-running by connecting the suppressor grid to earth and a capacitor between the suppressor grid and screen grid. The mode of operation can be followed by reference to Fig. 8.

Suppose that the valve is acting in the normal manner as a Miller integrator, that C_1 is discharging into the anode and that the linear decrease of anode volts dependent upon R_3C_1 is occurring. The screen grid will be at a relatively high potential and C_2 will be charged to this voltage.

At the end of the anode "run-down" the screen current will increase rapidly and the screen potential will drop. The capacitor C_2 will then carry the suppressor grid negative with respect to earth and cut off the anode current. C_1 will then commence to recharge through the anode load R_5 and at the same time C_2 will commence to dis-

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charge through R_7 and the screen grid so that the potential of the suppressor grid begins to rise. The time constants of these circuits are so arranged that C_1 becomes fully charged before C_2 has discharged sufficiently to allow anode current to flow. When the potential across C_2 has dropped sufficiently to allow the suppressor grid to become positive enough for anode current to flow, the "run-down" of the anode volts commences and the screen potential suddenly rises. C_2 then recharges through R_6 and the time constant is such that this is completed well before the end of the " run-down ".

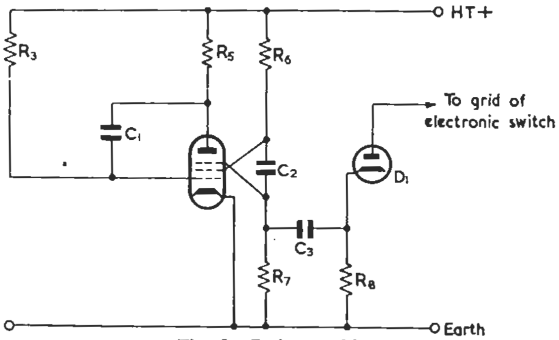

Fig. 8. Basic transition

The waveform of the suppressor grid voltage is differentiated by the network C_3R_8 and appears at the anode of diode D_1 as a sharp negative pulse which is used to trigger the electronic switch.

THE ELECTRONIC SWITCH

The circuit consists of a Miller integrator valve V_4, which produces single triggered strokes. The operating time of the electronic switch can be varied between one millisecond and 20 seconds by the switch S_3 and the potentiometer R_{16}. The anode " run-down " is stabilized by the voltage regulators N_1 and N_2, and the capacitors C_7 to C_{10} are adjusted so that with the slider of R_{16} at H.T. potential, the circuit produces square pulses of accurate length at the suppressor grid of V_4. These pulses are used for switching the audio-amplifier which will produce pulses of tone of known length, and also for the delayed trigger pulse for initiating the time-base of the oscilloscope at the end of the tone pulse.

THE AUDIO-FREQUENCY AMPLIFIER

The audio-frequency amplifier consists of V_5 and V_6 connected in push-pull. The frequency characteristic is flat to $\pm\frac{1}{4}$db from 25 to 10,000c/s and the overall gain is 20db. The input and output impedances are both 600 ohms.

The suppressor grid potential of the electronic switch is used as a bias for V_5 and V_6 which allows the circuit to operate either as a normal amplifier or carries the grids to a point well beyond cut-off. The amplifier is by this means disabled except when the electronic switch is " running down " and the suppressor grid is at zero potential, leaving the push-pull grids with their normal working bias.

Since V_5 and V_6 are connected in push-pull, anode voltage surges caused by the switching bias on the grids are in antiphase and cancel out. The potentiometer R_{29} adjusts the balance of the valves and makes possible an almost complete elimination of the switching surge. The

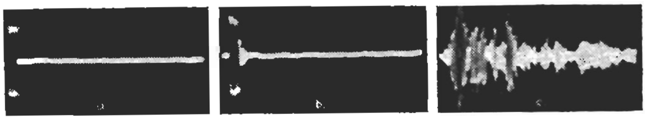
Fig. 9. (a) Pulse produced by tone pulser. (b) Same pulse after reproduction and subsequent pick up in an anechoic room. (c) Same pulse after reproduction and subsequent pick up in a reverberant room

amount of switching bias used to operate the amplifier is controlled by R_{21} and is adjusted in relation to the level of the tone fed into the instrument.

It should be noted that the switching surge is distinct from the transient produced by suddenly starting the tone pulse. The effect of the transient can be seen to be small by reference to Fig. 9 which shows (a) a pulse of 1,000c/s tone as produced by the tone pulser, (b) the same pulse after reproduction on a loudspeaker and subsequently picked up on a microphone in an anechoic chamber, and (c) in a reverberant room.

The equipment is very satisfactory in operation and some interesting results of pulse technique in studying the build up and decay of sound in auditoria have been described by Somerville.[4] The use of the equipment for tracing echo paths is also discussed.

In conclusion the authors wish to acknowledge the help of their colleagues in the B.B.C. Engineering Research Department, and in particular the work of Mr. S. H. Holmes on the mechanical layout. They are also indebted to the Chief Engineer of the B.B.C. for permission to publish this article.

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