Equipment for Acoustic Measurements

(Part 1)

A Portable General Purpose Microphone Amplifier Using Miniature Valves

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Research on the acoustics of rooms frequently involves the use of portable apparatus for making tests in studios and concert halls remote from the laboratory. The special equipment used in this work must be as compact and light as possible so that it can be handled easily by the engineers making the measurements. With these considerations in mind, apparatus for studio testing has been designed in the B.B.C. Research Department, using as far as possible, the types of miniature valves and other components which have become available since the war. The first of these, a general-purpose microphone amplifier, is the subject of the present article.

THE amplifier to be described has to operate in conjunction with the high quality microphones used in broadcasting equipment. The output from such microphones with weak sounds may be only 30db above the thermal agitation noise arising from the resistance of the microphone itself, while a full orchestra may produce an output some 50db higher. Special arrangements are therefore necessary in the amplifier to preserve the highest possible signal-to-noise ratio with minimum distortion.

The amplifier is required to work into a load having a nominal impedance of 600 ohms, and to present a substantially resistive output impedance of the same figure over the working frequency range. The maximum output required for the present purpose is + 20db relative to 1mW and it is desirable that the harmonic distortion of the system at this level should be below 0.5 per cent. In modern amplifiers using negative feedback, the distortion may be quite low even when the output is nearly equal to the maximum which the valves can deliver, but may increase rapidly with a slight rise in level. A percentage harmonic figure taken at a single output level may thus be misleading and it is therefore advisable to specify, in addition, the margin of safety between this level and the "ceiling" level at which actual clipping of the wave-form begins. In the present instance, a margin of at least 6db was called for, so that the output stage has to be capable of delivering at least 400mW (+26db) to the load.

In addition to the above requirements, an independent monitoring output is necessary to operate a loudspeaker for checking purposes, together with some visual indication of the outgoing level. The amplifier is required to transmit short-duration pulses and other rapidly fluctuating signals used in studio testing. A quick-acting indicator is therefore essential and since speech and music have also to be handled upon occasion, the standard B.B.C. peak programme metering circuit is used.

From the above, it will be seen that the new microphone amplifier fulfils the same functions as the portable apparatus used at outside broadcasts and is in fact similar in many respects to the existing equipment designed for that purpose in 1938.[1] However, by careful layout and the use of miniature components, the same facilities are provided by the present amplifier unit in a fraction of the space occupied by the earlier equipment. The new design has been in use in the Electro-Acoustics Group of the B.B.C. Engineering Research Department since 1947.

Circuit

The complete circuit of the amplifier is shown in Fig. 1. With the exception of the H.T. rectifier and the first amplifier stage, B7G based valves are used throughout. The circuit may be divided into the following parts:—

(a) a first stage, the gain of which is variable by altering negative feedback in two 10db steps.

(b) a continuously variable carbon track interstage attenuator of novel design, having a nearly uniform decibel scale over a large range.

(c) a three-valve line amplifier with push-pull output.

(d) a second circuit similar to amplifier (c) but having a low-impedance output for operation of a checking loudspeaker.

(e) a peak programme meter circuit operated from amplifier (d).

(f) a power supply unit using light-weight components.

These parts will now be described in more detail.

(a) FIRST STAGE (VALVE V_1)

The circuit of the first stage is based on that of an existing single valve unit amplifier designed by H. D. Ellis of the B.B.C. Designs Department and used in the new B.B.C. studio equipment.[2] In this circuit, the requirements of low distortion with large input signals and maximum gain with small input signals are met by the use of negative feedback, variable in 10db steps. In the present instance, the steps are arranged to give a maximum overall gain of 70, 80 or 90db, the setting used being determined by the maximum input to be handled. It will be noted that the feedback is taken from the anode circuit of V_1 to the grid and thus lowers the input impedance to that stage. The constants of the circuit are so arranged that with the minimum degree of negative feedback, the value of the input impedance at the grid of V_1 is correct for the termination of the input transformer T_1. Series resistors are automatically switched into circuit to maintain the load

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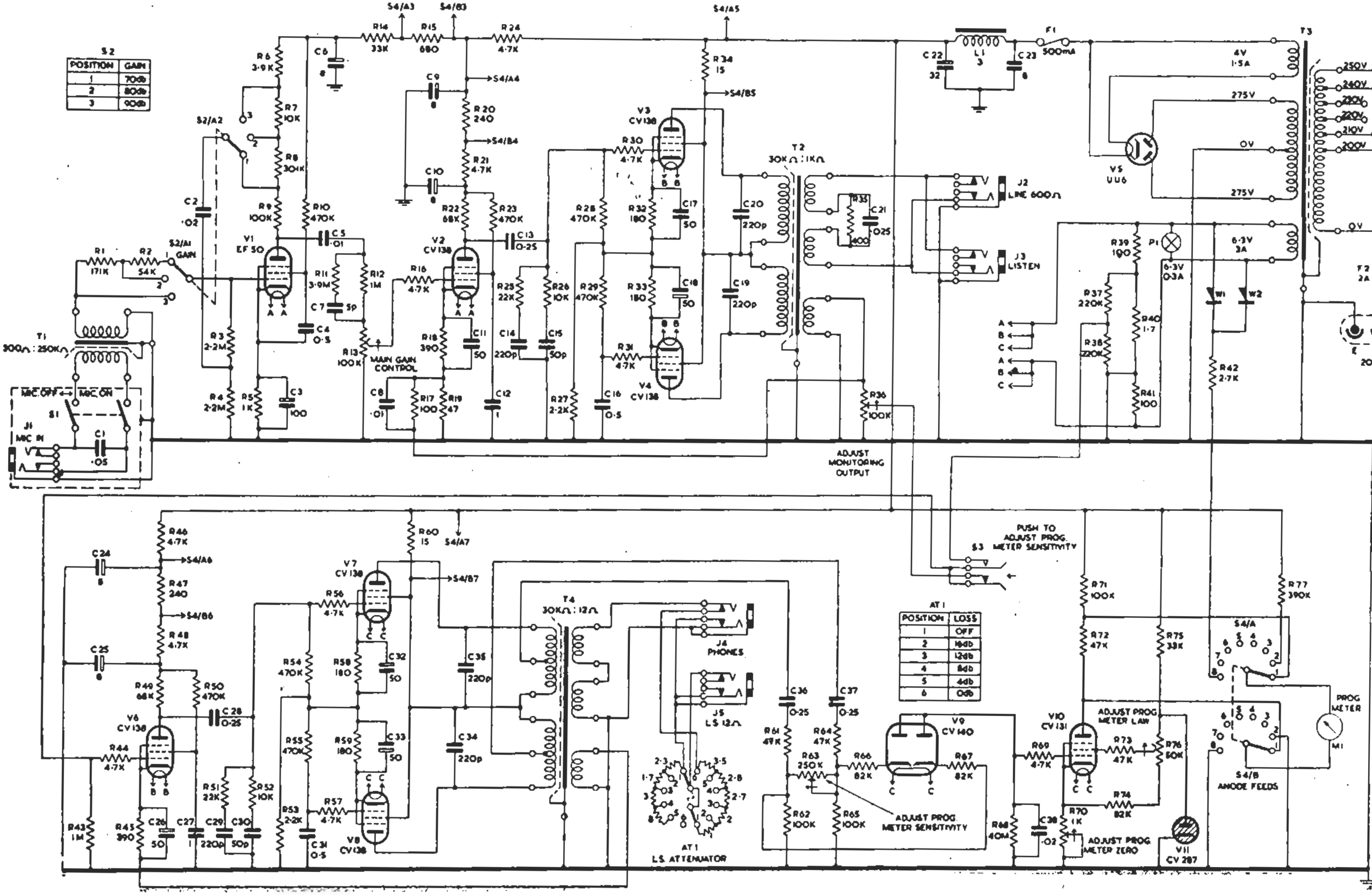


Fig. 1. The complete circuit diagram of the amplifier

on the transformer at the same value when the feedback is increased.

As in the earlier portable equipment,[1] T_1 is in effect, a filter circuit, a shunt capacitor C_1 being added on the primary side to complete the network formed by the leakage inductance, winding and circuit capacitances. This device makes it possible to use a relatively high step-up ratio—300 ohms : 250,000 ohms in the present instance—so that the signal level at the grid of V_1 is sufficient to allow A.C. to be used for the heater supply to this valve. Because of the high value of impedance at the grid of V_1, the secondary of T_1 must be so wound as to minimize the self-capacitance. Low-capacitance windings are necessarily wasteful of space and the result is thus a rather bulky transformer. Unfortunately, the size of T_1 cannot be reduced without also reducing the step-up and hence the signal-to-noise ratio. Therefore, when adapting the above circuit for the present purpose, T_1 was retained in its original form and, as will be seen later, the usual relative sizes of input and output transformer are actually reversed.

At the time when the amplifier was designed, miniature valves having a sufficiently low level of hum and microphony for first stage operation were not available. As a compromise, however, selected specimens of the EF50 are used.

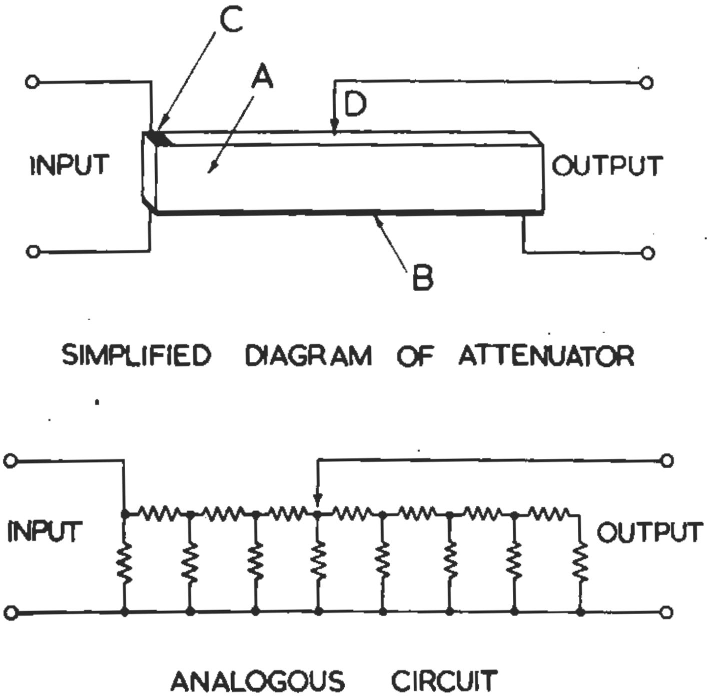


Fig. 2. The interstage attenuator

Even high-grade microphones may have slightly non-uniform frequency characteristics and it is convenient to compensate for these effects by equalization within the microphone amplifier. To this end, the circuit was designed with a certain amount of excess gain. Where no equalization is required, this extra gain is offset by the loss in a high series resistor R_{12} which is interposed in the input circuit of the second stage. The impedance of the circuit is high and a rise or fall in either high or low frequency response can therefore be brought about by the use of quite small series or shunt capacitors in conjunction with suitable values of resistors. Advantage has been taken of this arrangement to correct for a slight high frequency loss in the first amplifier stage by the addition of capacitor C_7 and resistor R_{11} shunted across R_{12}. The limit to the amount of equalization obtainable is set by the permissible variations in the load imposed on the anode of V_1, for any change in the voltage gain of that valve would affect the input impedance of the amplifier. Up to 10db of equalization can, however, be obtained without serious disturbance of the input impedance.

(b) Main Gain Control (R_{13})

A special type of carbon track attenuator provides a continuously variable gain control between the first and second stages. This attenuator was devised in 1946* in the B.B.C. Research Department by C. G. Mayo and R. H. Tanner. The principle of operation is illustrated by the simplified diagram of Fig. 2. The attenuator is formed by a block of resistance material A, of which the underside is covered with conducting material B. The input to the attenuator is applied between B and a fixed electrode C, while the output is taken between B and an electrode D which can be moved along the upper surface of A. The theory of this device is outside the scope of this article; a full mathematical treatment has recently been published in America.[3] As an approximation, the various series and shunt paths through the resistance material may be considered as roughly equivalent to the elements of a ladder network and the attenuation in decibels is proportional to the displacement of the slider D over a wide range. In the practical embodiment of this device as used in the the microphone amplifier, the block of resistance material is bent into a circular form and mounted in a 1½in. diameter casing, similar to that of a conventional carbon track potentiometer. Fig. 3 shows an exploded view of an experimental model using a resistance element made

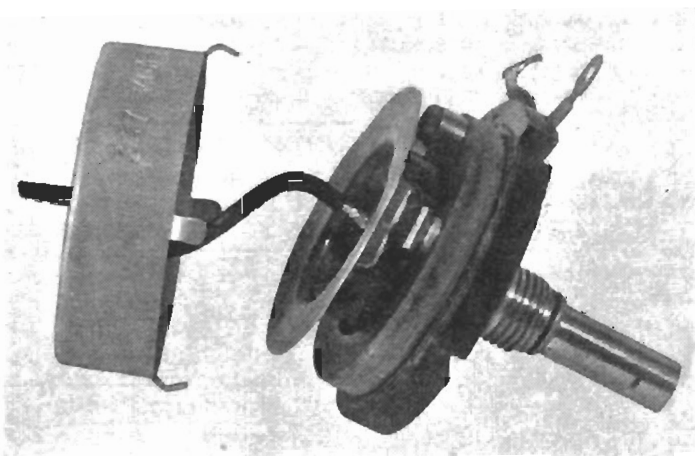


Fig. 3. The interstage attenuator showing dished screen around the output connexion

by the Morgan Crucible Co., Ltd. The output impedance of this attenuator, unlike that of a conventional potentiometer, does not become low when the attenuation is high. It is thus important to avoid stray capacity coupling between input and output, and the slider connexion is therefore carefully screened both inside the attenuator and in the external circuit. The useful range of the model illustrated is about 70db.

(c) Line Amplifier (Valves V_2, V_3 and V_4)

The line amplifier was designed as a standard unit for incorporation in this and other pieces of equipment.

The circuit involves no fundamentally new principle. A single-ended gain stage V_2 drives one valve, V_3, of a class-A push-pull pair of which the other valve, V_4, derives its signal from the voltage developed across the common cathode resistance R_{27}. Because of the high mutual conductance of the valves used, the degree of unbalance between the signal currents in the anodes of V_3 and V_4 is only of the order of 6 per cent. This method of obtaining a push-pull drive was originally described in an earlier publication.[1] Negative feedback is taken from a tertiary winding on the output transformer T_2 to the

* *Prov. Pat.* 963/47. *January* 10, 1947.

cathode of V_2, the loop gain in the audio-frequency band being 24db. With this degree of feedback, the impedance looking back into the secondary of T_2 is 200 ohms and a series resistance R_{35} is added to raise the output impedance of the amplifier to the required value of 600 ohms.

To reduce the voltage to be handled by the output transformer T_2, the anode load of V_3 and V_4 is made about 60 per cent of the optimum value, a compromise which makes it possible to keep the size of T_2 to $2^5/_{16}$in. by $1^9/_{16}$in. by $2^3/_{16}$in. high over tags and the weight to 7½ozs. Although each winding on the transformer is divided into two by a central partition on the spool, the total number of sections is, in effect, only three, one primary and two secondaries. With this arrangement of windings, the leakage inductance is sufficient to cause a slight loss in the 10-15kc/s region. To reduce the loss by increasing the number of sections would be difficult in such a small transformer and would lead to considerable complication of the feedback windings. Instead, the leakage inductance is approximately compensated over the frequency range concerned by shunting R_{35} with a capacitor C_{21}. By this means, the amplifier as a whole is made to present an almost constant output impedance up to 15kc/s.

Because of the small number of sections used in the output transformer, extensive distribution of the feedback winding is unnecessary. Each half of the primary winding is split to allow half of the feedback winding to be interposed. As the feedback winding consists of only a few turns of fine wire spread out in a single layer, the capacitance to earth introduced at the junction of the two parts of each primary winding is not sufficient to cause serious internal phase shift. To give the form of loop characteristics required for stability, the forward gain of the system is progressively attenuated at high frequencies by step circuits R_{25}, C_{14} and R_{26}, C_{15}, while a slight rise in response with a corresponding phase lead is introduced into the feedback path above the audio-frequency band by R_{17}, C_8.

The overload point of this amplifier is at approximately 750mW, of which 300mW are dissipated in R_{28} and 450mW are delivered to the external load.

(d) Monitoring Amplifier (Valves, V_6, V_7 and V_8)

For convenience, the input to the monitoring amplifier is taken from the feedback winding on the output transformer T_2 of the line amplifier. The circuit of the monitoring amplifier is basically the same as that of the line amplifier, but the output is designed to operate into a 12 ohm load. Since a low output impedance is desirable, the building-out resistance is omitted with a consequent gain in efficiency and the amplifier will thus deliver the full 0.75W to the load. With a modern high-efficiency loudspeaker, this power provides adequate sound level for checking purposes.

(e) Peak Programme Meter (Valves V_9 and V_{10})

This circuit is of the form standard in the B.B.C. Both halves of the signal wave are rectified by the double diode V_9 which charges capacitor C_{33} negatively. The voltage change across C_{33} is converted by the variable-μ valve V_{10} to a current change in the milliammeter M_1, which is made with a right-hand zero to avoid the necessity for a backing-off circuit. The operating characteristics of V_{10} are adjusted to give a roughly uniform decibel scale over a range of 20db.

The input to the double diode V_9 is taken from the output stage of the monitoring amplifier. The diodes necessarily impose on this stage a non-linear impedance load and to minimize the distortion thus introduced into the monitoring circuit, the programme meter input is tapped down on the primary of T_1 and further isolated by resistors R_{61}, R_{64} and R_{66}, R_{67}.

For many purposes, it is desirable that the reading of the programme meter should be proportional to the internal E.M.F. at the amplifier output and thus be independent of load impedance. Although the input to the monitoring amplifier and programme meter is derived, as already stated, from the feedback winding on T_2, the circuit constants are such that the above requirement is approximately met. Of the 600 ohms output impedance presented by the line amplifier, 400 ohms are provided by the resistance R_{35}, while the resistance of the transformer secondary winding accounts for another 130 ohms. The remaining 70 ohms represents the true output impedance of the stage and it is in effect the voltage across this impedance which is registered by the programme meter. It can readily be shown that if the programme meter is lined up to read correctly with the amplifier working into a 600 ohm resistive load, the maximum error involved in assuming the meter to read the true internal E.M.F. is ±½db for any load condition from short circuit to open circuit.

Since the programme meter is fed from the monitoring amplifier, the gain of the latter must be kept constant. Control of the loudspeaker volume is, therefore, affected by an attenuator AT_1 following the output transformer. This attenuator provides four steps of approximately 4db each and is designed to keep the impedance presented to the loudspeaker as low as possible without presenting too low an impedance to the monitoring amplifier output. Because of the degree of negative feedback used in the loudspeaker amplifier, the variation in the loudspeaker impedance with frequency has only a slight effect on the programme meter frequency characteristic. The maximum deviation arising from this cause is ±½db, and even this figure could be reduced, if necessary, by rough equalization of the loudspeaker impedance.

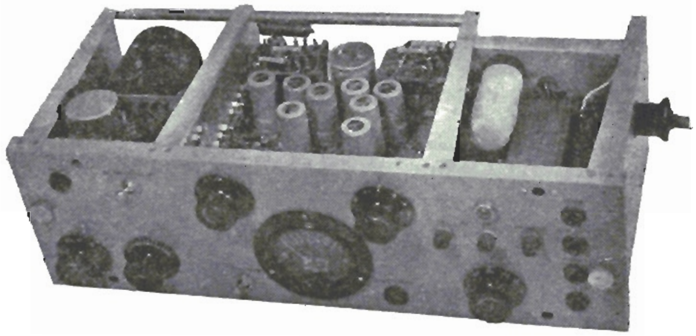


Fig. 4. The amplifier removed from its case

It might at first sight appear that the use of an attenuator between the monitoring amplifier and the loudspeaker would lead to overloading of the amplifier, but this is not the case in the present design. The adjustment of potentiometer R_{36} is pre-set so that the monitoring amplifier overloads at a programme meter reading corresponding to an output from the line amplifier 4db above the maximum rated level. Control of the main output thus automatically ensures sufficient margin of safety. The programme meter sensitivity is adjusted according to the output level required by potentiometer R_{63}, an internal calibrating voltage for this purpose being derived from the heater supply via resistors R_{37}-R_{41}. The heater voltage in turn is checked by the programme meter itself via the rectifiers W_1, W_2 and meter switch S_4, the mains tapping switch S_5 being adjusted as required to bring the reading to a fixed point on the scale.

(f) Power Supply (Valve V_5)

The iron-cored components in the supply circuit are designed for minimum size and weight. The mains transformer on the prototype was wound on a stalloy core, 3½in. by 3½in. by 3¼in. and weighed 4.3lb. It has been recently redesigned on a grain-oriented silicon iron core, the dimensions being reduced to 3¼in. by 3¼in. by 2¾ in. and the weight to 2.7lb. The smoothing choke is wound on

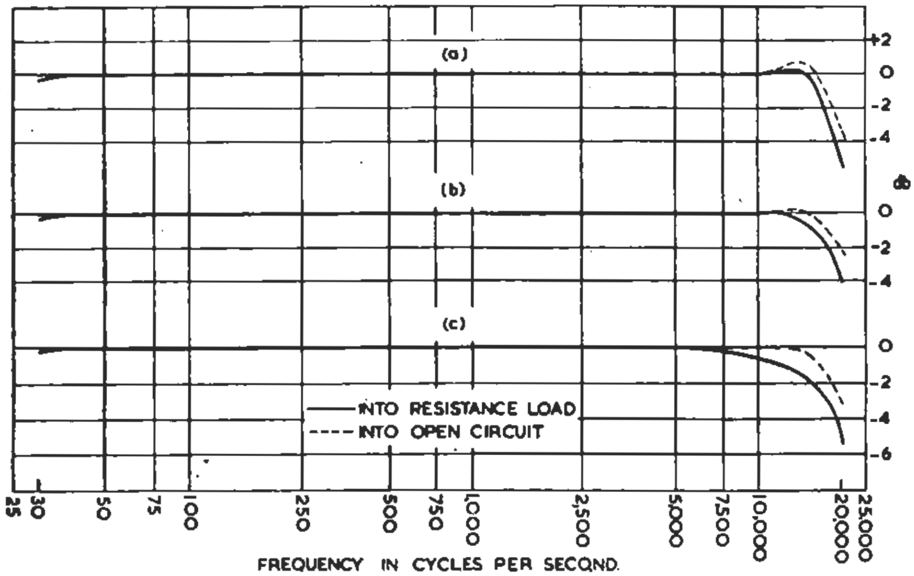


Fig. 5. Frequency response
(a) 600 ohm output, 70db gain setting
(b) 600 ohm output, 80db and 70db gain settings
(c) 12 ohm output, 70db gain setting

a radiometal core having a gapped centre limb. This form of stamping gives a small external field, an important point in compact equipment, while the sliding friction between laminations ensures a high degree of mechanical stability of the gap without the use of special core clamps. The choke is 1⅜in. by 1½in. by 1¼in. and weighs 4½ ozs.

Metering of anode feeds is carried out on the meter M_1, the values of the shunts being so adjusted that the normal feeds of the various stages correspond to the same point on the meter scale.

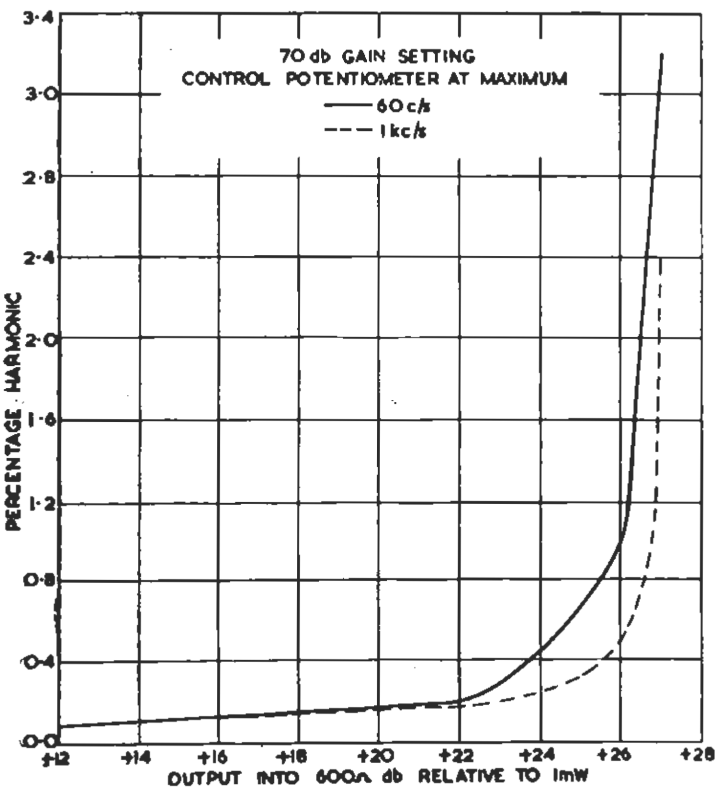
The power consumption of the amplifier is 48W at 200/250V, 50c/s.

Mounting and Layout

The complete apparatus described above is accommodated in a carrying case 17in. by 10in. by 6in. To achieve such a degree of compactness while retaining reasonable accessibility to components, careful layout and screening are essential; the voltage gain per stage is high and the frequency response can be seriously affected by quite small stray capacity couplings.

Fig. 4 is a photograph of the assembly out of its case, showing the upper side of the chassis. It will be noted that T_1, V_1 and V_2 are carried on a rubber-mounted sub-chassis at one end of the amplifier while the power unit is housed in a separate compartment at the other end.

The weight of the complete assembly as originally designed was 19¼lb. and with the new power transformer, the figure is reduced to just under 18lb.



Performance

The following figures give the performance of a typical specimen of the amplifier described above.

Frequency Response

See Fig. 5. The constancy of the output impedance with frequency can be judged from the small difference between the frequency response in the on-load and open-circuit conditions. This difference can be made even smaller by adjusting the value of C_{21} to suit individual output transformers, the leakage reactance of which varies slightly according to the tension used in winding them. In the case of the 12 ohm output, there is no compensation for leakage inductance and the output impedance therefore rises slightly at high frequencies. However, the cone loudspeaker used presents an inductive load so that no loss occurs in practice from this cause.

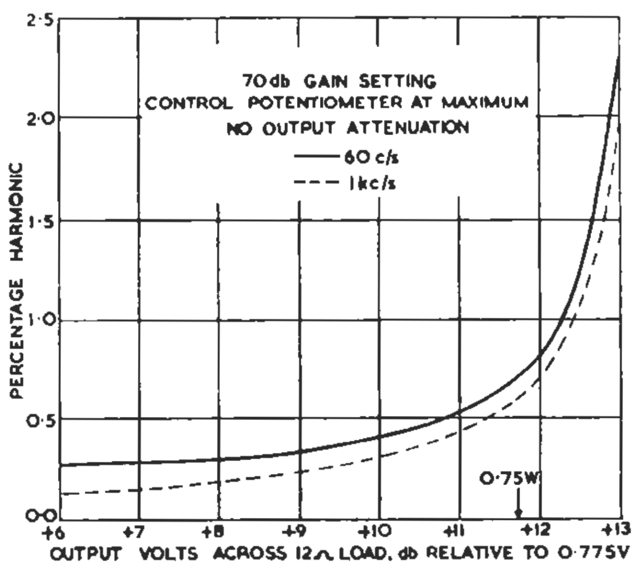
Noise

With main gain control set at maximum

Gain	Noise output, relative to 1mW
90	−38db
80	−44db
70	−48db

For comparison it may be noted that the calculated out-

Fig. 6 (left). Overall distortion
Fig. 7 (below). Distortion of 12 ohm output stage



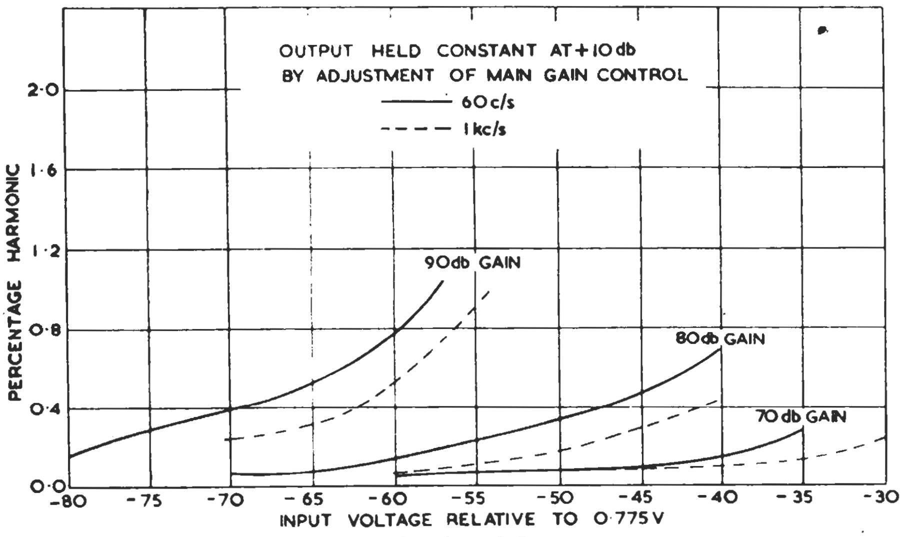


Fig. 8. Distortion of first stage

put from thermal agitation in the input circuit, including 300 ohms source, is −42db for a 15kc/s frequency band and 90db gain.

Distortion

To cover all possible gain settings, the circuit has been treated for the purpose of distortion measurement as two separate amplifiers in cascade.

All amplifier valves are operated under class-A conditions with sufficient negative feedback to keep the distortion small over the working range. In these circumstances, it is legitimate to take the total harmonic distortion as an indication of the degree of linearity of the system. An exception must be made in the case of the distortion introduced into the monitoring circuit by the rectifier of the peak programme meter. As this type of distortion is greatest immediately after the arrival of a signal, before the capacitor C_{38} has had time to charge, steady-state measurements are misleading and careful listening tests had to be carried out to check the performance of the amplifier in this respect.

Fig. 6 shows the overall distortion with the 70db gain setting and the control potentiometer at maximum. Here, the distortion is principally that of the line amplifier.

Fig. 7 shows the distortion of the 12 ohm output stage under the same conditions.

Fig. 8 shows the distortion introduced by the first stage, the output to line being restricted to a low value so as to keep other distortions small.

Acknowledgments

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