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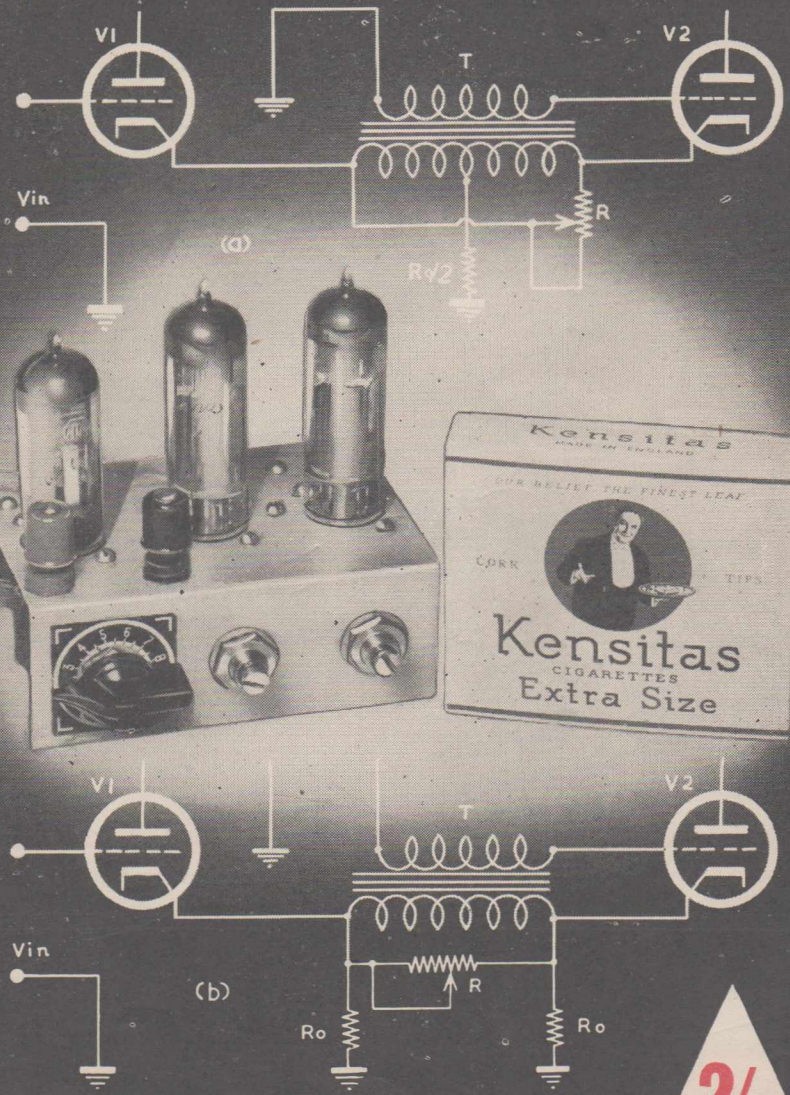
A high-quality audio amplifier for your radio receiver, radiogram, recorder, PA system, or as a modulator for a transmitter, the "Parry" Cathamplifier will do the job with greater efficiency and at a lower cost. Inside are described Cathamplifiers with outputs ranging from 4.5 to 40 watts. Performance: ✪ Frequency response, flat from 30 to 20,000 c/s. ✪ High inherent stability. ✪ Negligible distortion. ✪ High sensitivity, less than 0.5V. input gives full output.



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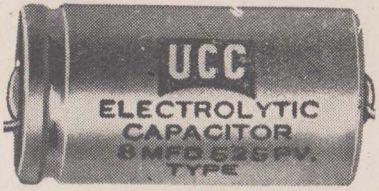

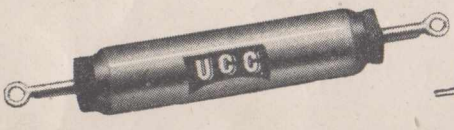

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The Mingay Publishing Company, publishers of Australia's only radio-electrical trade weekly newspaper "Radio Electrical Weekly" first published details of the "Cathamplifier" in WEEKLY on 24/2/50. Other articles followed in succeeding issues.

So great was the demand for back numbers containing the articles dealing with the "Cathamplifier," that they were quickly exhausted. Furthermore, the interest, not only of the radio trade, but of others was aroused, and to meet the demand for information, all available material has been collated and re-published in this booklet, together with much additional information not included in the original articles.

The circuit of the amplifier is quite new, and a patent has been applied for by the designer Mr. C. A. Parry, A.M.I.R.E. (Aust.), a consulting radio engineer, who desires to acknowledge his indebtedness to Fergusons' Transformers Pty. Ltd., for providing the original transformers required for the 15-watt amplifier, and also to Mr. R. Meadows, A.M.I.R.E. (Aust.) (WEEKLY's Radio Technical Editor) who built the prototypes and carried out most of the measurements on them.

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Introduction

AUDIO - FREQUENCY amplifiers have always proved a popular subject with technical readers, and over the years there has been a constant search for the "El Dorado" popularly termed "high fidelity." Actually it is not a difficult matter to produce an amplifier having good quality reproduction characteristics, but just what constitutes "high fidelity" is a concept that seems to vary with the times. Improvements in components and circuitry have been partly responsible for a tightening of generally-accepted principles, and far greater attention is given in these days to linearity, harmonic distortion, and similar subjects than in the past.

Although many good amplifiers have been produced over a period of years, their cost has often made them prohibitive except for the few. The "Williamson" amplifier is an example of this. In contrast, the "Cathamplifier" gives excellent results with less than a dozen resistors, two capacitors, and the necessary valves and transformers, in a very small space.

In the past, adherents of good quality have been inclined to be wary of the use of transformers in AF amplifiers, and not entirely without cause. In the case of the "Cathamplifier" a good *output* transformer is just as essential as in any other type of amplifier, but the cathode transformer is not critical in its specifications, as it is used in a low-impedance degenerative circuit.

Two practical versions of the "Cathamplifier" are described in these pages, the first, a 15-watt unit comprising a pair of EL35's driven by a 6AU6, and the second, a miniature version using three Philips Innovals, capable of delivering between 4.5 and 9.4 watts depending on the output transformer used. In addition, some suggestions are made for the benefit of those who would like to experiment with a high-powered unit of about 40 watts.

Basic Principles

Initial Considerations

In Mr. Parry's opinion, the ideal requirements for a basic amplifier are:

(a) Size. Small, simple, compact.

(b) Response. Within ±1db from 30 to 15,000c/s.

(c) Adequate speaker damping.

(d) Low harmonic distortion (less than 2.5%).

(e) High sensitivity. (For 15W output, less than 0.5V input.)

(f) Good inherent stability.

(g) Low noise.

In a conventional PP amplifier, the push-pull output stage works at half normal gain, or, in other words, twice the driving voltage is required compared with a single-ended output stage. In the "Cathamplifier," only sufficient drive for one of the PP valves is required, since the other valve is driven by the cathode transformer. In addition, in normal phase splitter systems, an additional valve is required to obtain 180° phase inversion, and contributes only 1.8 gain, whereas in the "Cathamplifier," full gain is obtained from all

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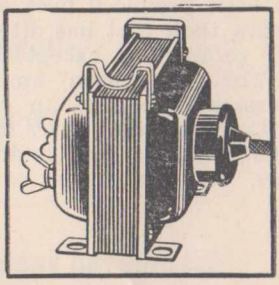

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stages, while at the same time the cathode transformer drives the second grid in its proper phase relationship. This high gain feature enables a large degree of feedback to be incorporated, or alternatively, allows the omission of an earlier amplifying stage. In addition, elimination of the phase splitter valve and associated components saves space and reduces the cost.

These points will be made clear on reference to Fig. 1, where the cathode transformer marked "T" in the various diagrams is connected in the cathode circuits of the output valves. The circulating current of these valves produces a voltage across the secondary, the magnitude of which can be varied by means of the resistor "R" and thus ensures that voltage of the correct magnitude and phase is applied to the grid of V2 to maintain properly - balanced push - pull operation.

As the high-impedance input to the first valve of the output pair is unbalanced, the stage can be driven by a high-gain pentode amplifier. The influence of the cathode transformer is relatively small on a feedback loop, and as adequate sensitivity is available with only one preceding stage, the feedback can be applied over the two stages, ensuring much greater inherent stability. Even with feedback, a standard pick-up will deliver more than sufficient input signal to drive the amplifier fully.

Because of the method of driving the PP valves, Mr. Parry has named his circuit "Cathamplifier," and the basic circuit of the output stage is shown in (a), while (b) shows a variation which does not require a centre-tapped transformer, and (c) is an arrangement permitting both AC and DC balancing of the output valves.

The modification in 1(d) also

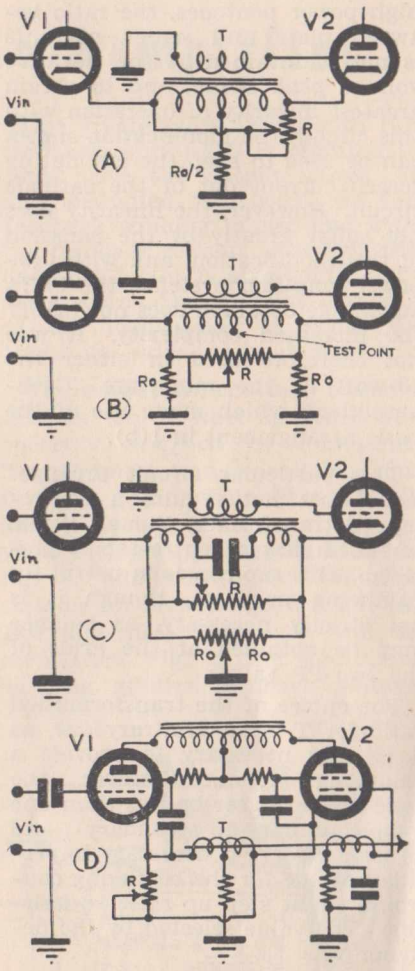

FIGURE 1

(a) Basic circuit of the "Cathamplifier." (b) A modification which was used in the 15W. unit. A centre-tap is not necessary. (c) Both AC and DC balancing is permitted in this arrangement. (d) A variation which keeps the circulating screen current out of the cathode circuit, and so maintains the ratio between plate and screen currents at the negative voltage peak swing. This system also provides a means of matching the output grid circuits, which may be necessary in higher-power assemblies.

may be of interest. In the case of high-power pentodes, the ratio between plate and screen currents is not maintained at the negative voltage peak swing, and to obtain greatest linearity of operation with this circuit, the modification shown can be used to keep the circulating screen current out of the cathode circuit. However, the linearity does not suffer greatly by the omission of this modification, and with low-power amplifier systems, the extra advantage obtained does not justify the increased complexity. It was not therefore used in either the 15-watt or the miniature "Cath-amplifier," which made use of the basic arrangement in 1(b).

This particular circuit arrangement does not require a centre-tapped transformer, though it will be noted that a centre-tap is provided. This tap comes in useful for balancing purposes, though it is not strictly necessary, as balance may be obtained at the grids of the two PP valves.

The choice of the transformation ratio for T is an arbitrary one, as it is only necessary to provide a balancing signal. However, the ratio should never be less than one (whole primary to secondary), and as some reserve is necessary to provide latitude for the balancing control, a slight step-up ratio is desirable. The value selected by the designer was 3.3.

The transformer itself is not critical and almost anything is good enough providing the primary centre-tap is accurately located. The efficiency can be fairly readily checked by observing the waveform from the centre-tap at balance. Observation on the CRO here tells whether the fundamental AC plate currents are equal. If not, they do not cancel, and the residual waveform shows a strong fundamental component. If the fundamentals cancel, only distortion products remain, and of course if the fundamentals are equal you can't do any better with any system.

Although a variable feedback control was used in the first models of the 15 and 9-watt amplifier, it is recommended that a fixed resistor be used. The value shown in the circuit diagrams is approximate, and provides a useful starting point. To obtain a required degree of feedback, a variable control can be connected temporarily and adjusted in accordance with the data given under "Adjustments" on page 17, then replaced with a fixed resistor of equivalent value.

Performance

Even without feedback, the frequency response of this type of amplifier is remarkably good. In the 15-watt amplifier it is only down 2.75db at 20,000c/s *without feedback*. Even with 15db feedback, only 0.23V input drives the amplifier fully. It is essentially linear to 15 watts, and stability with and without feedback is quite satisfactory, and no further precautions are necessary to avoid low frequency instability. Further details on the performance of the 15-watt amplifier will be given in the next section together with a complete description of the circuit arrangement.

A 15-Watt "Cathamplifier"

The circuit arrangement of the 15-watt amplifier is shown in the diagram in Fig. 2. It will be noted that a miniature 6AU6 is used to drive the push-pull output valves (EL35's). The cathode transformer marked "T" is used to derive the 180° phase difference for the grid of the second output valve, and this portion of the circuit is similar to the basic arrangement marked (b) in Fig. 1. The 100Ω potentiometer is the balance control, and this is adjusted so that the effective signal at the grid of the second output valve is of the same magnitude but 180° out-of-phase, as that applied to the grid of the first output valve.

Feedback, it will be noted is taken from a special winding on the output transformer, which has a tap allowing a lower percentage of feedback if desired, with consequent greater gain. Even with full feedback, only 0.23V is required to fully drive the output valves. It may be noted that with the full feedback winding in use and with the feedback resistor as shown, the damping factor is about 0.16 — in other words, the effective damping of the loudspeaker is about six times its value without feedback.

The output transformer actually used in the 15-watt amplifier was specially designed by Fergusons' Transformers, and is available from retailers and wholesalers. It is known as type OP51, and is provided with a tapped feedback winding in addition to VC windings suitable for matching to 2.3, 2.7, 8.6, 12.5 and 15.5Ω loads. As will be seen from Fig. 2, the additional winding applies feedback voltage

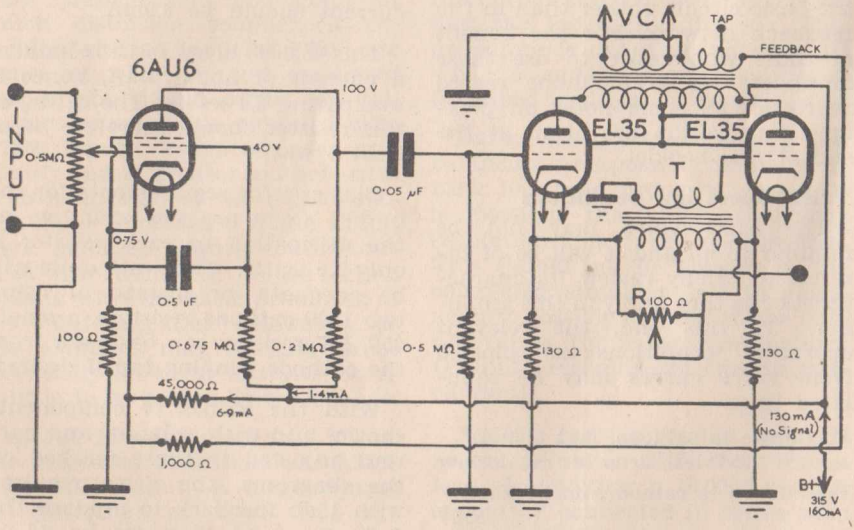

Figure 2. Circuit arrangement of a "Cathamplifier" system to give 15W high-quality output. The open connection to the primary of the cathode transformer "T" is to facilitate balancing of the output valves.

back to the cathode of the driver stage.

The designer favors this method of feedback, though some readers may prefer to dispense with the special output transformer, and use a standard unit, in which case the feedback can be taken either from a voltage divider system across the output valves, or from the voice-coil winding (preferably the latter (see Fig 4). This last system is used in the low-powered unit described on page 13.

Some readers may consider that bass and treble boost should have been included by adaption of the feedback circuit. Such arrangements complicate the design, and often reduce the speaker damping, introduce instability, or cause more trouble than they cure. A basic amplifier should be regarded as an integral part of the loudspeaker system, and the characteristics of the amplifier must overcome and supplement any shortcomings of the loudspeaker system. Correction circuits should be placed between the input (pick-up) and the basic circuit, rather than in the feedback network. For the benefit of those who desire to use these amplifiers for gramophone record reproduction, some notes on pick-up compensation are given at the end of this booklet.

Valve Operating Conditions

The EL35 valve may not be familiar to all and it will be of interest to briefly review its characteristics as they apply in this amplifier. To this end, the relevant operating conditions as plotted from valve curves may be tabulated thus:

E_p (anode to cathode, max signal) 295V less drop in transformer

E_{sc} (screen to cathode, max signal) 295V

Bias (no signal) 17.5V

Bias (max signal) 20V

I_p (no signal, $\times 2$) 130mA

I_p (max. signal, $\times 2$) 150mA

Bias resistor (per valve) 135Ω

HT supply (max. signal) (20+295) 315V

Transconductance —

(low signal) .. .. 8.5 mA/V

(medium signal) .. .. .. 6.0 mA/V

(large signal) .. .. .. 5.4 mA/V

The AC plate resistance per valve for the PP output stage will be 22,500Ω, the recommended load per valve 2,250Ω, and the plate-to-plate load 4,500Ω.

Operating conditions chosen for the 6AU6 driver were:

E_p 100V

E_{sc} 40V

Bias 0.75V

I_p 1.0mA

I_{sc} 0.4mA

I_c 1.4mA

G_m 2.5mA/V

HT Supply 315V

Since the required bias is 0.75V, a bleed resistor of 45,000Ω can be used as shown in Fig. 2. The bleed current should be 6.9mA.

This 45,000Ω bleed resistor handles a current of about 7mA, hence is dissipating 2.4 watts. The rating of this resistor should therefore be at least 5 watts.

Bias resistor requirements for the output stage are not exacting, as the dissipation in each resistor is only 1.5 watts. Two-watt units will be adequate, or instead of using two 130Ω cathode resistors, a single 65Ω, 5W resistor can be taken from the cathode winding tap if desired.

With the values of components shown, and with voltages and current adjusted to those marked on the diagrams, the drive required with 15db feedback to produce the full output of 15 watts is: 15 $\times$ gain reduction/gain of 6AU6 stage $=$ 15 $\times$ 5.6/290 $=$ 0.29V, which is close to the obtained figure of 0.23V,

indicating that full output will be available when driven by a standard high-impedance magnetic pick-up.

Performance

Tests and measurements were exhaustive, and covered a period of several months. The final results confirmed the designer's mathematical data, and proved that a really good amplifier can be built at a low cost.

Even without feedback, the frequency response curve was remarkably good, being flat within —2.75db to 20,000c/s without feedback, and within —1.8db at 20,000c/s with feedback, and at 15,000c/s, was only down 1.5db. The curve was absolutely flat to 30c/s, the lowest test frequency available.

Linearity was plotted in steps of 10%, i.e., output voltage plotted against input voltage at 1,000c/s, and a straight line resulted up to nearly 15 watts, a gradual tapering off at the higher output being expected, despite the use of an efficient transformer. The point at which distortion commenced coincided with an input of 0.28V, the figure at which it was estimated full output should occur, but full output actually was obtained with 0.23V input. As mentioned previously, even greater output with perfect linearity at the higher output could be obtained if the circuit were modified slightly in accordance with circuit 1(d) in the section dealing with the basic principles of the "Cathamplifier." However, as the amplifier may be said to be essentially linear to 15 watts, there is little to be gained by the change.

At full 15 watts output at 500c/s, the measured distortion was 0.33% with 0.23V input. A measurement of distortion at 60c/s was attempted, and although much less than 1% was obtained at 15 watts output the actual figure could not be measured exactly.

These figures are well within the 5% quoted as an acceptable maximum for good fidelity by some of the reliable textbooks, and as the amplifier is seldom likely to be used constantly at full output, the measurements thus indicate that for normal use, the actual total distortion is so low as to be negligible.

To check the behavior of the amplifier under conditions of varying HT supply, a 1,000c/s signal was fed to the amplifier from an audio oscillator, and the volume control was adjusted to give an output of 12 watts. The HT voltage was decreased by 135 volts to check the stability, and the change of output level was less than 0.1db. The inherent stability with and without load was also checked, since an amplifier inclined to be slightly unstable will usually show unmistakable signs of it when the load is removed. No extra precautions are required to prevent low-frequency instability. The square wave response at 30c/s is excellent.

Before the amplifier can be used, the output stage must be balanced, and the feedback adjusted. This procedure is described on page 17, while a suitable power supply is described in detail on page 21.

During the process of testing and balancing, and possibly before feedback has been properly phased, it is possible that high frequency oscillation may be encountered. This should not be present in the completed amplifier, but to guard against possible damage to the output valves, the valve manufacturer (Philips) recommends certain precautions.

A 100Ω resistor should be connected in series with each screen lead. In addition, a 10,000Ω resistor should be connected in series with each output valve control grid lead. The resistors may be removed after final adjustments providing oscillation does not recommence.

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A Miniature "Cathamplifier"

While the 15-watt amplifier described in the preceding section will interest those who want something more than average power, there is particular interest in a lower-powered version for use in radio receivers, recorders, and record players. WEEKLY therefore developed a miniature version using the new Philips 9-pin all-glass "Innovals," and though the circuit arrangement (Fig. 4) is similar to the 15-watt version, a few minor modifications have been made. The amplifier is capable of excellent reproduction with less than 0.3% distortion and has chassis dimensions of only 3 x 4 x 1½ inches. From this, with a suitable power supply, a virtually - distortionless output of 9 watts can be obtained at the plates of the output valves, which means that anything from 5 to 8½ watts can be delivered to the voice-coil of the loudspeaker, depending on the quality of the output transformer used.

The unit as built up is purely an amplifying system and requires a separate power supply, of which the required characteristics are given later, together with details of a suitable unit. Because of this, the overall dimensions could be restricted to but little more than that required by the valves used, and it was found that the width of the chassis was dictated by the dimensions of three standard potentiometers (4 in.), though the left-hand control only need be retained (volume control . . . see photograph reproduced as Fig. 3), and the other two controls (feedback and balancing) could be of the fixed or semi-fixed type, thus reducing the size still further. The cathode transformer, five other resistors,

Figure 3. General view of the Miniature "Cathamplifier," shown alongside a cigarette packet for size comparison.

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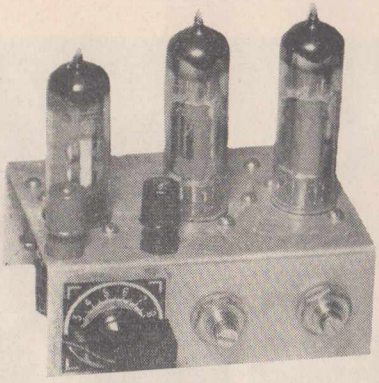

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and two capacitors are mounted below the chassis.

In keeping with the general reduction in size made possible by the simple circuit and the compact "Innoval" valves, a check was made of the power-handling requirements of the resistors, and although ¼W resistors could have been used in all cases except one, half-watt units are more easily procurable, and were used except for the bias resistor on the output stages where, although the power dissipated is below 1 watt, a 2-watt resistor was used. It is interesting to note that IRC make a 2-watt 82Ω resistor which is sufficiently close to the 85Ω shown in the diagram (Fig. 4).

An interesting feature is replacement of the usual 0.5μF screen bypass capacitor by a 5μF electrolytic of the miniature type (UCC type CE30D) having a working voltage of 50. The change was made to reduce space, and tests showed that leakage was negligible. However, a nasty peak on the leading edge of a square wave was experienced, and this eventually was traced to the earthing of the metal casing of this capacitor. Evidently this provided sufficient bypassing of the cathode to bypass the feedback circuit, hence this capacitor should be insulated from earth. A tiny UCC 0.05μF 200WV capacitor (type CT34H) was used for coupling, but here the metal case may be earthed if desired.

Valves

The new Philips "Innoval" 9-pin series valves were used, the driver being a 6N8 duo-diode pentode. The diode plates are not used, but if the amplifier is to be built as part of a radio receiver, the existing detector may be dispensed with, and the diodes in the 6N8 used for detection and AVC; the first valve then becoming detector, AVC, and first AF stage. The output valves, which are capable of delivering 9.4 watts in PP, are type 6M5 pentodes. Special 9-pin sockets are required for these three valves and as it is doubtful whether all readers are as yet in possession of socket data, the pin numbering has been marked on the circuit diagram.

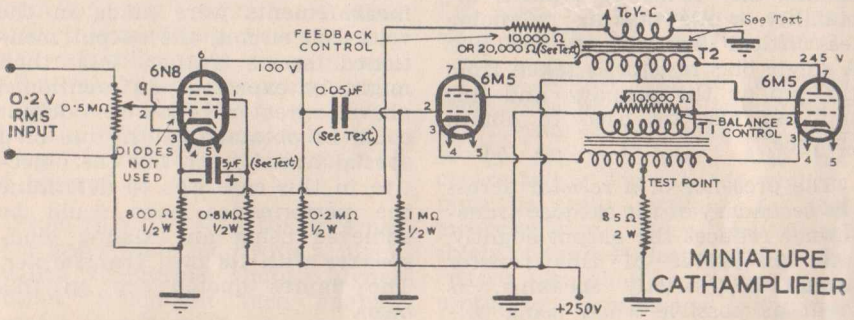

Figure 4. Circuit arrangement of the Miniature "Cathamplifier" which can deliver up to 9W output with a suitable output transformer.

The Cathode Transformer

Although the cathode transformer used in the 15-watt amplifier could have been used, a miniature one made on a special nickel-iron stalloy core was made by Nova of Sydney for trial and was found quite suitable for the

job. It is stressed that where space is not a factor (as when building the power supply on the same chassis), the standard size, which is made by Fergusons' Transformers, and also by Nova, is also suitable, and in fact may be used with amplifiers rated at up to 60 watts.

A 100Ω potentiometer (anything up to 500Ω works just as well, but may be critical in adjustment), can be connected across the cathode winding for balancing if the original 15-watt circuit is favored, but in that case it would be wise to connect a 10,000Ω fixed resistor (½ watt) across the secondary, as there may be a tendency to high-frequency oscillation. In the final version, balancing was obtained by using a 10,000Ω pot across the secondary, automatically reducing the Q of this winding and overcoming any tendency towards instability, while making balancing less critical than with the 500Ω pot. A single bias resistor is taken from the tap on the primary, and this tap can also be used to obtain balance.

The presence of a resistor across the secondary of the cathode transformer reduces the output slightly, and the value of this resistor should be, strictly speaking, as great as possible when using primary balancing. Alternatively, any tendency to HF oscillation if this resistor is high, or left out, can be minimised by using a capacitor instead of it. Probably only about 50 — 100$\mu\mu$F would be adequate.

The Output Transformer

It has already been pointed out that this amplifier is designed to use a standard speaker transformer instead of a special output transformer with a built-in feedback winding. However, no modification is required if a good-quality output transformer is used.

Not more than 50% efficiency can be expected from a standard speaker transformer, and it should be noted that this transfer, or insertion, loss from plate circuit to voice-coil always applies and can only be reduced to a minimum by use of a specially-designed output transformer. Even so, the loss will seldom be less than 1db, which means that only about 0.8 of the rated power of an amplifier is actually fed to the loudspeaker, while with standard speaker transformers half the rated power may be lost in the transformer.

This point is emphasised to avoid misleading impressions when reading the following material and adverse comparisons with other amplifier designs. The tests on this particular amplifier were made using a standard speaker transformer with a rated loss in the vicinity of 3db and as output measurements were made in the voice-coil circuit, the output mentioned seems rather less than might be expected. As mentioned above, greater effective output could be obtained by the use of a special transformer, but the objective in this case was to determine the performance that could be achieved using an existing loudspeaker with its own transformer. The figures quoted are on this basis.

The loudspeaker used had a VC impedance of 2 ohms (Rola 12-O) and a feedback factor of 4 is obtained when the feedback resistor is about 10,000Ω, but this only applies if the same VC impedance is used, and will have to be varied as explained later, for other VC impedances though 2.3 and 2.7Ω VC will require little if any change.

The plate-to-plate load of the original transformer was 10,000Ω, and at this figure the total distortion is extremely low. The maximum usable output to the loudspeaker voice-coil is in the vicinity

of 5 watts under these conditions.

Just before going to press with this Handbook, checks were made with a laboratory-type multi-impedance high-quality output transformer capable of being adjusted over a wide range of reflected impedances, and the load on the plates was then varied from 5,000 to 15,000Ω with some interesting results.

With a load of 7,000Ω, 9 watts in the voice-coil circuit was easily obtained. A resistive load was placed across the VC winding, instead of the loudspeaker voice-coil, and the feedback loop was removed, the input signal being reduced so that the output was still 9 watts. A CRO was then connected to the amplifier output, and a check made on the waveform with a square-wave input signal. It was found that the distortion was somewhat higher under this condition. Feedback was then re-applied, and the gain control advanced again to bring up the output to normal, and it was noted that the distortion was reduced to below 1%, and this is low enough to be ignored.

From this it is seen that the use of a lower plate load with a high-quality transformer enables higher output, which in turn enables greater feedback to be applied, thus reducing the distortion to a negligible value. Attempts to increase feedback with an inexpensive 10,000Ω transformer led to oscillation, but this condition was not met with the more expensive transformer.

If 5 watts is enough for requirements, the 10,000Ω load will therefore be satisfactory, but for a 9-watt output, the 7,000Ω load is recommended. In the latter case the output transformer should be a good one if the full output is to be realised.

Construction

The socket holes must be made large enough for the bases of the valves to fit inside. No shielded leads are necessary, but the cylindrical shield inside the contacts of each valve socket should be earthed. The cathode resistor on the first stage is small enough to be soldered directly back to this connection, and all three resistors on this stage are mounted in an upright position to conserve space.

It is a wise plan to take the leads from the cathode transformer to a resistor strip in case they have to be reversed later. Also the centre-tap of the cathode winding must be easily available for test measurements. Keep the metal shield of the 5μF electrolytic off the chassis. Another resistor strip is useful for terminating the power cable, the seven connections being: Common (B—, CT of heater winding, and VC), two plates of the O/P stage, B+, VC feedback lead, and two heater leads.

Adjustments

Balancing

Temporarily disconnect the lead to the feedback control. Any tendency towards instability will be more noticeable thus. Check HT input, and adjust to the required output voltage on load (315V in the 15W amplifier, and 250V in the miniature version) by means of a resistor in the power supply (referred to on page 22), then check plate, screen and bias voltages with a VTVM.

Feed a 0.2V signal to the input,

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and turn up the gain control until the output is about 2/3 maximum. Thus working on an O/P figure of 4 watts with a 2Ω VC,

$$E = \sqrt{(WR)} = \sqrt{(4 \times 2)}$$

$$= \sqrt{8} = 2.8 \text{ volts approx.}$$

An exact reading is not required. Connect the VTVM probe between the CT of the cathode winding and earth using a 10V AC range, and adjust balance control for minimum reading. This may not be zero, but it should be a very low reading. The voltage remaining is a measure of the normal distortion voltage present after the fundamental voltages have been equalised and cancelled. Switch to the low AC range and complete the adjustment. Check the voltages at each output grid to ensure they are the same, adjusting the balance control slightly if necessary. As the voltage here may be several volts, use the 10V range on the VTVM.

Alternatively the balance control can be adjusted until the AF voltages on the two P-P grids are equal, but this necessitates two measurements each time the balance control is adjusted, hence the former method is preferred, with a final check on the grids to ensure that the adjustment is accurate. As the balance control is left set at the balance position, it can be mounted under the chassis.

Many constructors will not have a VTVM, CRO, or AF oscillator available, but if not, balancing can still be effected with reasonable accuracy with the aid of headphones and a low-voltage AC source. The AC source may be one of the heater windings feeding the amplifier or a separate transformer.

Connect a potentiometer of any convenient value across the AC source and earth one side of the potentiometer to chassis if the transformer winding is not already earthed (which it will be if one of the heater windings is used). The moving arm of the potentiometer then connects to the amplifier input terminal so that a 50c/s AC signal is applied.

In the case of the 15W amplifier, the centre-tap of the cathode transformer is left open for balancing and it is only necessary to connect the headphones between the centre-tap and earth. Adjust the AC potentiometer until the output is about 2/3 of maximum as judged by the ear, then adjust the balance control until the hum in the head phones is at a minimum. The adjustment should be quite sharp. Then disconnect the headphones. Fairly high resistance headphones should be used and their resistance will not greatly affect the results, because bias is obtained by separate resistors at the cathodes of the output valves.

When balancing the 9W amplifier by this means, it is advisable to connect a 200Ω resistor from each 6M5 cathode to earth, open-circuiting the earthed end of the 85Ω resistor. Connect the headphones between the open end of the resistor and earth, then balance for minimum hum as before. A 1,000c/s audio signal will permit better balance than a 50c/s AC signal. Remove the 200Ω resistors, and solder the 85Ω resistor back into place.

It should be noted that the balance control will have a different setting if several adjustments are made at various output levels, since the balance is effective only at the setting made. However, since the input signal varies over an average value, this has no detrimental effect on the final reproduction, but the point is raised because some readers, rechecking the setting at a different level to that at first used, may wonder what has happened!

It is the average effect on a vary-

ing signal that counts. Although this may seem to indicate non-linearity, a check (see description of the 15-watt amplifier) shows that the amplifier is essentially linear up to full output, after which it tapers off.

If a square-wave generator and CRO are available, a square wave fed into the amplifier at 1,000c/s (even with an inexpensive O/P transformer) should retain the characteristics of the original.

Feedback

Feed a steady signal to the amplifier and adjust the gain control until the output is about two-thirds of maximum. The exact setting is not critical as it is necessary only to obtain a convenient output voltage level as a basis for adjustment of the feedback circuit.

This done, the feedback circuit should be connected and the resistor adjusted until the output level is reduced to about one-quarter of its initial value in the case of the 9W amplifier, and about one-sixth in the case of the 15W amplifier. These settings will provide the recommended feedback factors of about 12db and 15db, respectively, for the two amplifiers.

If the amplifier oscillates when feedback is applied, it means that the voice-coil (or feedback) winding of the output transformer is wrongly connected, and the leads should be reversed, connecting the earth to the side where the feedback resistor was connected, and vice versa.

It may be noted at this point that oscillation may occur *before* the feedback circuit is connected, causing an output reading to be obtained with no signal input. If this occurs, the secondary connections on the cathode transformer should be reversed. This point should be checked before the feedback circuit is connected (which is another reason for disconnecting the feedback loop before balancing) as the feedback may prevent the oscillation and give misleading results.

It is not practical to give exact output level figures for the feedback adjustment, because of the variety of loudspeaker voice-coil impedances which may be used. However, as in the case of the balancing operation, the equation $E = \sqrt{(WR)}$ may be applied to obtain the voltage present in the voice-coil circuit.

Taking as typical examples 2 and 8 ohm voice-coil circuits for the 9W and 15W amplifiers, respectively, and working at output power levels of 4W (assuming a standard transformer) and 10W, the initial voltages before feedback is applied work out at something like 2.8V and 9V. This means that the correct feedback setting for the smaller amplifier will be reached when the output voltage is reduced to about 0.7V, and for the 15W amplifier at 1.5V.

Having made this adjustment, and if everything is in order, it should be possible to restore the initial output level simply by turning up the input gain control on the amplifier. If this is not possible, either insufficient driving signal is available or some portion of the amplifier is out of adjustment (incorrect voltages or resistor values) causing gain to be insufficient to offset the loss due to the feedback. As designed and built, with the values and valves shown, gain of these amplifiers is more than adequate for this purpose, so that failure to obtain sufficient gain can be taken as an indication of a wiring, valve or component fault.

A 40-Watt "Cathamplifier"

No actual work has been done on a 40-watt version of the "Cathamplifier," but some consideration has been given to the matter, and for the benefit of readers who care to try such an amplifier for themselves, the following suggestions may be useful.

Type EL34 valves would provide an output in excess of 40W, and the circuit would remain the same as the 15W "Cathamplifier" except that the two cathode resistors should be varied around 300Ω each so that the total zero signal plate current is about 140 — 150mA.

The plate-to-plate load to be reflected by the output transformer would be about 4,400Ω and the current per winding 100mA max DC, with a rating of 40 — 50W. A 6AU6 should easily drive the output valves, and the same cathode transformer as in the 15W version can be used.

The efficiency of the output transformer should not be less than 80%, and the inductance of the primary at maximum signal should give less than 0.2db loss at 40c/s. No feedback winding will be required, the output being fed back from the VC as in the miniature version of the "Cathamplifier."

The overall gain should not be reduced more than 2 or 3 times by the medium of overall feedback with an amplifier of this power, unless very detailed measurements can be made. It should be possible under the conditions suggested to obtain full output for less than 0.5V input and with less than 2% distortion.

A particular point worth trying is to add a network to the second grid, as shown in Fig. 1(d) in the introductory section of this book, to give the same grid current effects as apply to the first output valve, which may be necessary with a job of this power. A measurement of linearity with and without this network would quickly show its value. The network could comprise a 10,000Ω fixed resistor placed across the secondary of the cathode transformer, one end of which connects to the grid of the second output valve. The other end of the winding, instead of being connected to earth, connects to a 0.05μF capacitor and a 0.5MΩ resistor in parallel, the other ends of which connect to earth.

Power Supplies

No power supplies were included on the chassis of the two amplifiers built. Primarily these amplifiers were developed as substitutes for existing amplifier systems in which power supplies were available. In addition, a workshop power supply having a power transformer with tappings either side of the secondary centre-tap was available for such projects as these. The taps were merely varied to give the required output voltage on load (315V at 160mA in the case of the 15W amplifier, and 250V at about 90mA for the 9W amplifier).

There is no reason why the power supplies should not be built on the

same chassis as the amplifiers provided the usual precautions are taken to prevent hum being induced. Both supplies are conventional, and use capacitor input. Suitable arrangements will now be described.

15-Watt Unit

A suitable power supply for the 15-watt amplifier is shown in Fig. 5. The rectifier is a 5V4G, which will deliver 175mA output current. Socket connections are shown on

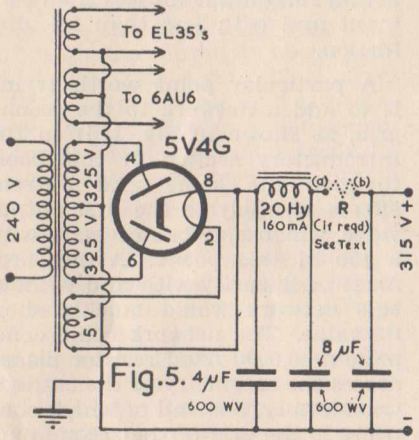

Figure 5. Power supply unit for the 15W "Cathamplifier." The resistor "R" is inserted only if the output voltage on load exceeds the required value of 315V.

the diagram. Reference to valve curves shows that with a 4μF input capacitor, and a transformer rated at 325V either side of the secondary centre-tap, the output voltage on load is approximately 315V.

Variations in transformers, DC resistance of filter chokes, and in mains voltage may cause the output voltage to be different, and 10V either way may be ignored. If however the mains voltage is high enough to cause the output voltage to be higher than say 325V, a dropping resistor (R on the diagram) should be inserted as shown.

The value of the resistor (if required) should not be more than a few hundred ohms if the amplifier is operating properly. The rating of the resistor in watts should be (in this instance) approximately 1/20th of its resistance in ohms. For example, if it is found that a 200Ω resistor reduces the voltage on load to 315V, the rating of the resistor should be 200/20 = 10 watts.

The simplified calculation is based on the fact that the wattage rating should be approximately twice the wattage dissipation, i.e. As $I = 160/1{,}000$, $2I^2 = 32/625$ or approximately 1/20th. If the resistor is not required, points (a) and (b) should be joined.

Both the 6.3V windings should be used, one for the output valves, which have a fairly heavy load requirement, and one for the heater of the first valve. Use the centre-tapped winding for the 6AU6, and earth the tap. One side of the winding supplying the EL35's also should be earthed.

9-Watt Unit

The power supply for the 9-watt unit is a lower power replica of the previous power supply, and is shown

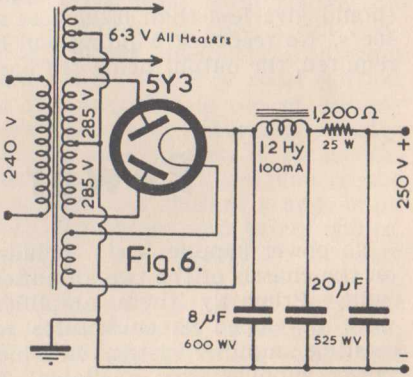

Figure 6. Power supply unit for the Miniature "Cathamplifier." The 1,200-ohm dropping resistor will usually be required but may be adjusted to alter the output voltage as necessary.

in Fig. 6. The secondary voltage either side of centre-tap need only be 285V, and as the required load is only 80mA, a 100mA transformer is ample.

The series resistor was found necessary, even with the low voltage transformer, and though the voltage could have been reduced by using a smaller input capacitor, it was found advisable (because of the extremely good response of the amplifier to low frequencies) to keep the hum level as low as possible by using an input capacitance of 8μF. The voltage dropping resistor and following capacitor also tend to reduce the hum, which is inaudible at a distance of a few feet from the speaker. The resistor drops the voltage on load to 250V, and here again, a tolerance of 10V is permissible. A 5Y3 rectifier was used. If the voltage differs considerably, and the amplifier is pulling its proper load, the 1,200Ω resistor should be varied until the voltage is 250V. The rating of this resistor should be about 25W.

The input capacitor used should not exceed 8μF, though the other capacitors may be of the 20μF 525WV type. The higher capacitance provides ample filtering with a 12H filter choke.

In the miniature "Cathamplifier" all heaters were connected to one of the 6.3V windings, the centre-tap of which was earthed.

Microphone Operation

If the amplifier is to be used with a low-level microphone, an additional stage will be required. Either a 6AU6 or a 6N8 may be used for this stage, and suitable constants will be 0.5MΩ plate resistor, 2MΩ screen resistor, 0.5μF screen bypass, 1,000Ω cathode resistor (bypassed with a 25μF electrolytic if greater gain is required) and a 0.05μF coupling capacitor. The ends of the screen and plate resistors can connect directly to the B-plus connection through a 50,000Ω resistor, the junction of the three resistors being bypassed to chassis by an 8μF electrolytic.

The coupling capacitor should connect to the "live" end of the amplifier volume control. For the preamplifier stage a fixed grid resistor of 1MΩ will be suitable.

Gramophone Pick-Up Compensation

As mentioned earlier, any compensation required should be looked upon as an accessory, rather than as part of the amplifier, and it should be interposed between the signal source and the grid of the first amplifying stage. No matter how flat the frequency response of an amplifier may be, the results are not necessarily pleasing, especially on recordings.

Commercial recordings are made with a cutter which has a lateral or side-to-side movement. Two methods of cutting are commonly employed, viz., constant amplitude, and constant velocity. In the constant amplitude system, the cutting stylus moves a constant distance each side of centre as the frequency varies, for a constant input to the cutting head. In the constant

velocity method the cutting stylus moves with constant lineal velocity as the frequency varies. Thus as the frequency decreases the stylus increases the width of its swing in order to maintain its velocity, while in the constant amplitude system, the stylus moves with greater lineal velocity at high frequencies than at low frequencies, since it has to travel a fixed distance from centre in a given period of time.

The constant amplitude system has the disadvantage that at high frequencies, the velocity is so great that the playback needle will not track properly, and difficulty is also experienced in finding record materials which can be cut accurately at high frequencies. On the other hand, the constant velocity system has the disadvantage that at low frequencies, the amplitude of the swings may be so great as to cut into adjacent grooves. As a result, most commercial discs are cut by using constant amplitude at low frequencies where its advantages are greatest, and constant velocity at high frequencies, for the same reason.

The cross-over frequency of the two systems is usually in the vicinity of 500c/s. Constant velocity is a characteristic of crystal pick-ups and cutters, and if a record were cut with a crystal cutter by the constant amplitude method, and reproduced by a crystal pick-up, the output would be substantially constant at all frequencies. This is also true in the case of a disc cut with a magnetic cutter at constant velocity, and reproduced by a magnetic pickup. As discs are cut by using both methods however, neither type of pickup will give a flat response. The crystal pickup being amplitude sensitive will lose output above 500c/s, while the magnetic pickup being velocity sensitive, loses output below 500c/s. This loss is roughly 6db per octave above the crossover frequency for the crystal, and 6db per octave below the crossover frequency for the magnetic pickup.

This assumes perfect cutters and pickups, but in fact resonances and other effects sometimes compensate for the differences, and sometimes do not. It so happens that increased gain is seldom required at the high-frequency end of the band, firstly because few standard recordings contain frequencies much above 5,000c/s, while surface noise "scratch" becomes annoying at the HF end of the AF band. Some of the newer recordings are made to handle high frequencies, particularly some of the newer types of plastic recordings which have received much publicity overseas.

For reasons explained above, it will be seen that no bass compensation is required if a crystal pick-up is used, but in that case the volume control should be increased to at least 2MΩ, and a series resistor of several megohms should be placed between the "high" lead of the pick-up and the input terminal. If however a magnetic pickup is used, the 6db loss should be compensated by a bass boost system. This will only be necessary if the pick-up is not already compensated, some of the commercial pickups available already having suitable compensation (HMV for example).

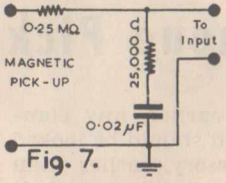

Fig. 7.

Figure 7. Simple bass boost network for use with an uncompensated magnetic pick-up.

Fig. 7 shows a simple bass boosting system that can be inserted between a magnetic pickup and the grid of the first amplifier stage to give a bass boost of 6db per octave.

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•

FOR the 15 watt Cathamplifier you will need a Cathode Transformer Type MT109, an Output Transformer Type OP51 (this has multiple tappings on the secondary to suit all standard voice-coil impedances), a Power Transformer Type PF142, and Filter Chokes Type CF109.

•

FOR the 4.5 to 9 watt Cathamplifier you need Cathode Transformer Type MT109, Power Transformer Type PF245, and Filter Chokes Type CF106. Either the 10,000 Ω or 7,000 Ω push-pull transformers are available, the 10,000 Ω (Type OP85) having multiple secondary tappings to suit any standard speaker voice-coil impedance, or the 7,000 Ω PP transformer which can be supplied to suit any single VC impedance which should be specified when ordering. Order by indicating the required VC impedance thus: 7,000PP/2.3 (for a 2.3 Ω VC), 7,000PP/8 (for an 8 ΩVC), etc.

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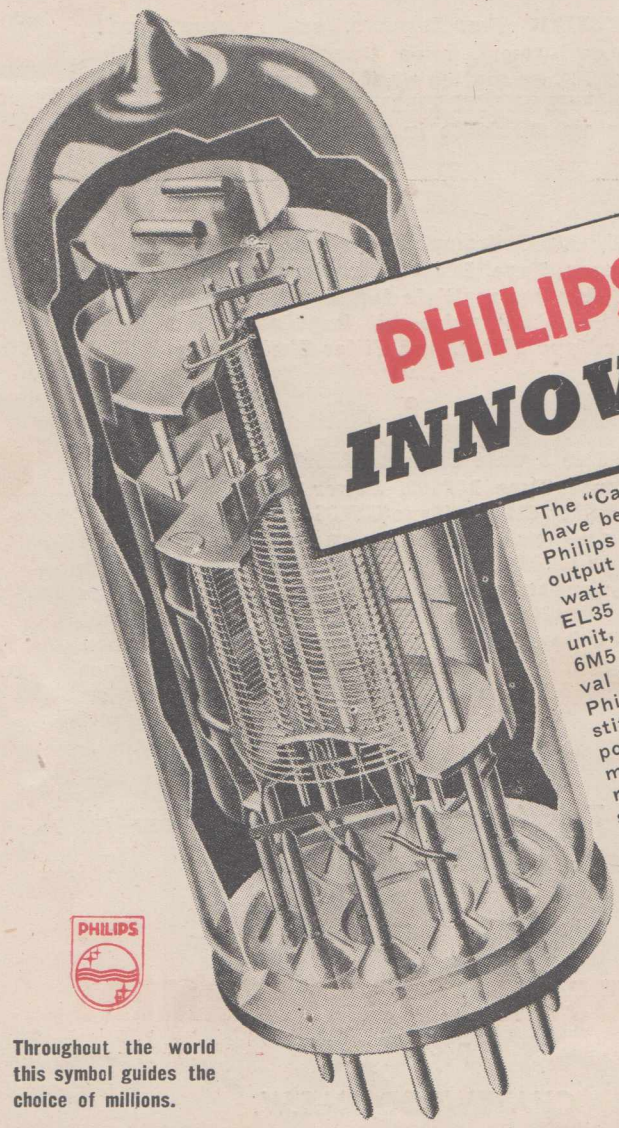

PHILIPS
INNOVAL

The "Cathamplifier" circuits have been designed around Philips high sensitivity output pentodes. The 15 watt amplifier uses the EL35 and the 9 watt unit, the Innoval type 6M5 as well as Innoval type 6N8.

Philips Innoval constitutes the only real post-war development in valve technique. Its construction provides the means by which even the most complex valve types can be made in miniature form — with more ruggedness, greater efficiency and uniformity than ever before.

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