# Design for a 20-Watt High Quality Amplifier

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## *Choice of Valves and Operating Conditions*

IN recent years remarkable improvements have been made in the field of sound reproduction. Progress in the design of pickups, amplifiers and loudspeakers, coupled with the introduction of high-quality disc and tape recordings and v.h.f. sound broadcasting has set new standards for discriminating listeners. The amplifier and associated control circuits form the core of a sound-reproducing system and much interest has been focused on their design requirements and the manner in which high quality can be achieved.

The basic requirements of an amplifier designed for high-quality sound reproduction have previously been discussed in these pages[1, 2]. It is proposed here to discuss further some aspects of high-quality amplifier design, with emphasis on the output stage, and it is hoped to describe in a subsequent article a design for a high-quality 20-watt amplifier using 25-watt high-slope pentodes in the output stage.

The principal features of a good amplifier can be briefly recapitulated:

1. Very low harmonic and intermodulation distortion.
2. Linear frequency response in the audible range.
3. Good response to signals of a transient nature.
4. Low phase shift in the audible frequency range.
5. Low hum and noise level.
6. Adequate power output to allow peak passages to be reproduced without overload.
7. Low output resistance to provide electrical damping for the loudspeaker system.

**Output Stage.**—Although the power-handling capacity of an audio amplifier is not the most important factor from the listening point of view—a low distortion level being usually judged pre-eminent—it is nevertheless of prime importance from the point of view of the designer.

It is generally considered that for realistic reproduction of orchestral music in the home a peak output power of 10-15 watts is required, assuming the efficiency of the loudspeaker system to be about 5%. Apart from loudspeaker efficiency, the required power depends on the size and acoustic nature of the room and to a lesser extent on the taste of the listener. Thus, whilst 10 watts is found to be adequate in many, perhaps, the majority of, cases conditions in large rooms and small halls may merit a power reserve of at least 20 watts.

There exists a choice of two basic forms of output stage from which an effective output of 10-15 watts can be delivered to the voice coil of the loudspeaker. These two well-known forms of output stage are:

1. The Class AB push-pull pentode or tetrode stage.
2. The Class A or Class AB push-pull triode stage.

The choice between these is largely a balance between economy and performance.

**Pentode Output Stage.**—The use of pentodes or tetrodes of the 12-watt anode dissipation class, operated in a conventional Class AB push-pull stage, enables an effective output of 12-13 watts to be obtained easily, assuming an output transformer efficiency of about 80%. This latter value is typical of present practice. The appropriate supply voltage, limited by valve ratings, is about 300-320 volts. The overall power efficiency of such a stage is fairly high, being 50% for a typical stage employing Mullard EL84 output pentodes. Harmonic distortion is, however, of the order of 3%-4% at full output, and in consequence a high degree of negative feedback is necessary to reduce distortion to low levels, say below 0.5% at rated output.

The conditions for Class AB operation normally recommended and published by the valve manufacturer are based on measurements made with continuous sine-wave drive. The bias under zero-drive conditions and the anode-to-anode load resistance are so chosen that optimum performance is achieved when the working point of the valves is displaced under drive conditions. This displacement is due to the influence of increased anode and screen-grid currents in the cathode bias circuit. For a typical output stage on a 310-volt supply using EL84 pentodes the rise in cathode current, and thus, cathode bias voltage at full drive, is about 40% with a sinusoidal input voltage.

When such a stage is used in the reproduction of speech or music, however, operating conditions are rather different. The mean amplitude of the input

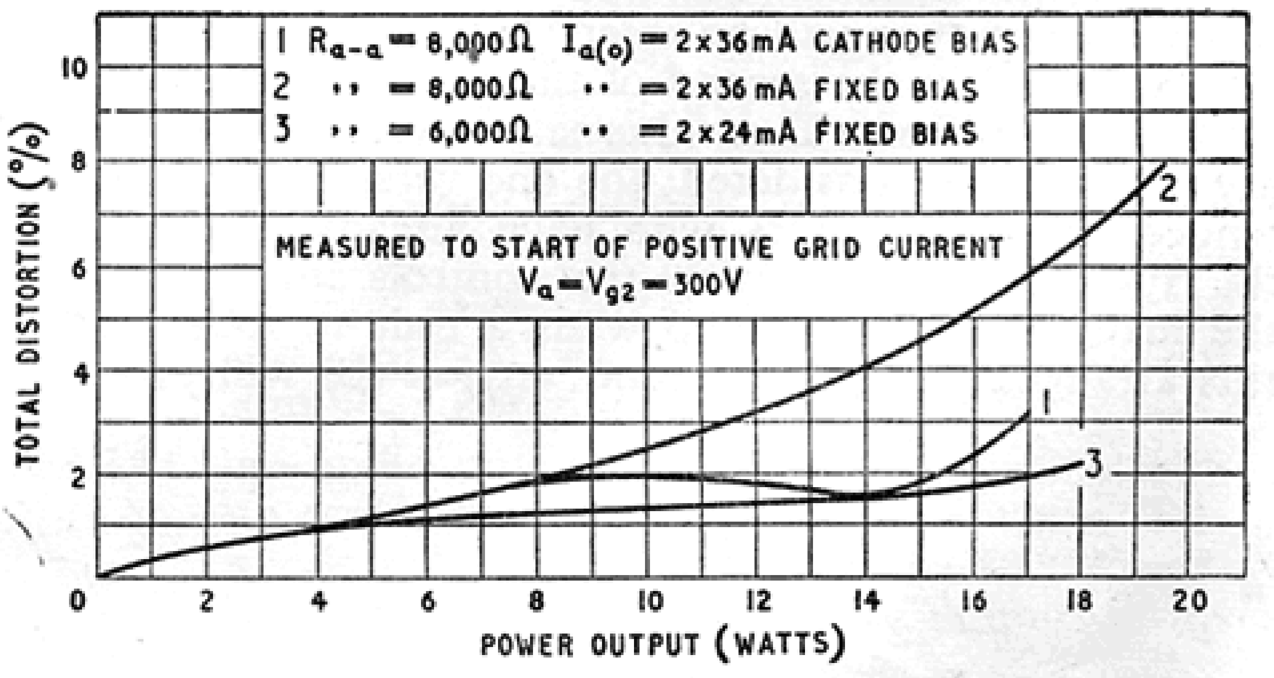

*Fig. 1. Comparison of distortion curves under steady-state sinusoidal input conditions for a pair of EL84 valves in Class AB push-pull (1) with normal cathode bias, (2) with fixed bias under the same conditions, (3) load reduced for optimum fixed-bias operation.*

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signal is now very small compared with the peak values which occur from time to time and thus the mean variation of cathode current is also very small. Due to the relatively long time constant in the bias network the displacement of the working bias, even under peak signal conditions, is small enough for the stage to be considered as working with virtually fixed bias. If the normal Class AB stage (cathode biased) is measured under the corresponding fixed-bias conditions with a sine-wave input, it is found that at high output levels distortion is greater than when cathode bias is used. These two conditions are illustrated for the Mullard EL84 output pentode by curves 1 and 2 in Fig. 1. The quiescent bias is the same in both cases, curve 1 showing normal published operation with cathode bias, curve 2 operation with fixed bias. These results indicate that in practice, a cathode-biased Class AB stage designed on a sinusoidal drive basis will produce increased distortion when peak passages of speech or music are being reproduced.

One method of improving performance in practice is to adjust the quiescent operating conditions in the output stage so that they are nearly optimum for fixed bias working, although cathode bias is still used. This entails a smaller standing current and lower anode-to-anode load impedance. These changes result in larger variations in the instantaneous anode and screen-grid currents when the stage is driven, but the effect of these is at least partially compensated since the time constant in the cathode bias network has been increased at the same time. The excursion of the working bias is still kept very small under driven conditions.

It is found that good short-term regulation of the power supply is ensured by the use of large value (50$\mu$F) electrolytic capacitors for anode and screen-grid feeds. Peak currents corresponding to near overload conditions are effectively supplied by the capacitors with a reduction in line voltage of well under 0.5%, and the instantaneous power-handling capacity of the stage is not impaired.

Such a design, combined with a high degree of negative feedback (26 db), which includes the output stage and output transformer, is an alternative operating condition in the output stage of the 10-watt Mullard high-quality amplifier circuit[3, 4] and has proved very satisfactory in practice. A secondary feature of the use of these operating conditions is that the 12-watt output valves each run at a mean anode dissipation of only 7.5 watts. The corresponding fixed bias conditions in this case are illustrated in curve 3 of Fig. 1.

This form of operation is, however, suitable only for use in speech or music reproduction and cannot be used with a sine-wave input without excessive distortion. For this reason it is difficult to measure directly the distortion levels which obtain under practical conditions.

A second method of improving performance, described later, is to use distributed load conditions in the output stage. Depending on the precise loading used, the variation in anode and screen-grid currents can be reduced to such a level that almost identical performance is obtained under cathode and fixed bias conditions.

**Triode Output Stage.**—A low level of inherent distortion can be obtained in a push-pull triode stage operating under virtually Class A conditions. It is found that with 25-watt pentodes or tetrodes strapped as triodes a power output of 12-15 watts can be obtained at harmonic distortion levels below 1% using a supply voltage of 430-450 volts.

Maximum power output and the corresponding distortion vary appreciably with the value of load impedance and Fig. 2 illustrates typical performance of the Mullard EL34 high-slope output pentode, triode-connected in a push-pull stage operating slightly below its rated anode dissipation of 25 watts.

For anode-to-anode load impedances below 7,000Ω either a common, or separate cathode resistors (bypassed) can be used; above 7,000Ω improved operation is obtained with an unbypassed common cathode resistor. Operating conditions approach Class A as the anode-to-anode load impedance is raised and optimum performance for high-quality output stages is obtained with a load impedance of about 10,000Ω. An output of 14 watts is then delivered by the valves with total harmonic distortion well below 1%.

This type of output stage has found favour for a number of years in high-quality amplifiers giving about 12 watts effective output. Because of the low inherent distortion less negative feedback can be used to give acceptable linearity as compared with that required in pentode or tetrode output stages giving similar power output. Furthermore, in 3- or 4-stage amplifier designs, with most of the feedback applied over the whole amplifier, including the output transformer, it is then possible to achieve increased margins of stability for a given distortion level.

**Distributed Load Conditions.**—Increasing interest is being shown in various forms of distributed loading in the output stage[2]. These involve the application of negative feedback in the output stage itself. In the simplest form, the screen grids of the output valves are fed from suitably positioned taps on the primary of the output transformer and the stage can be considered as one in which negative feedback is

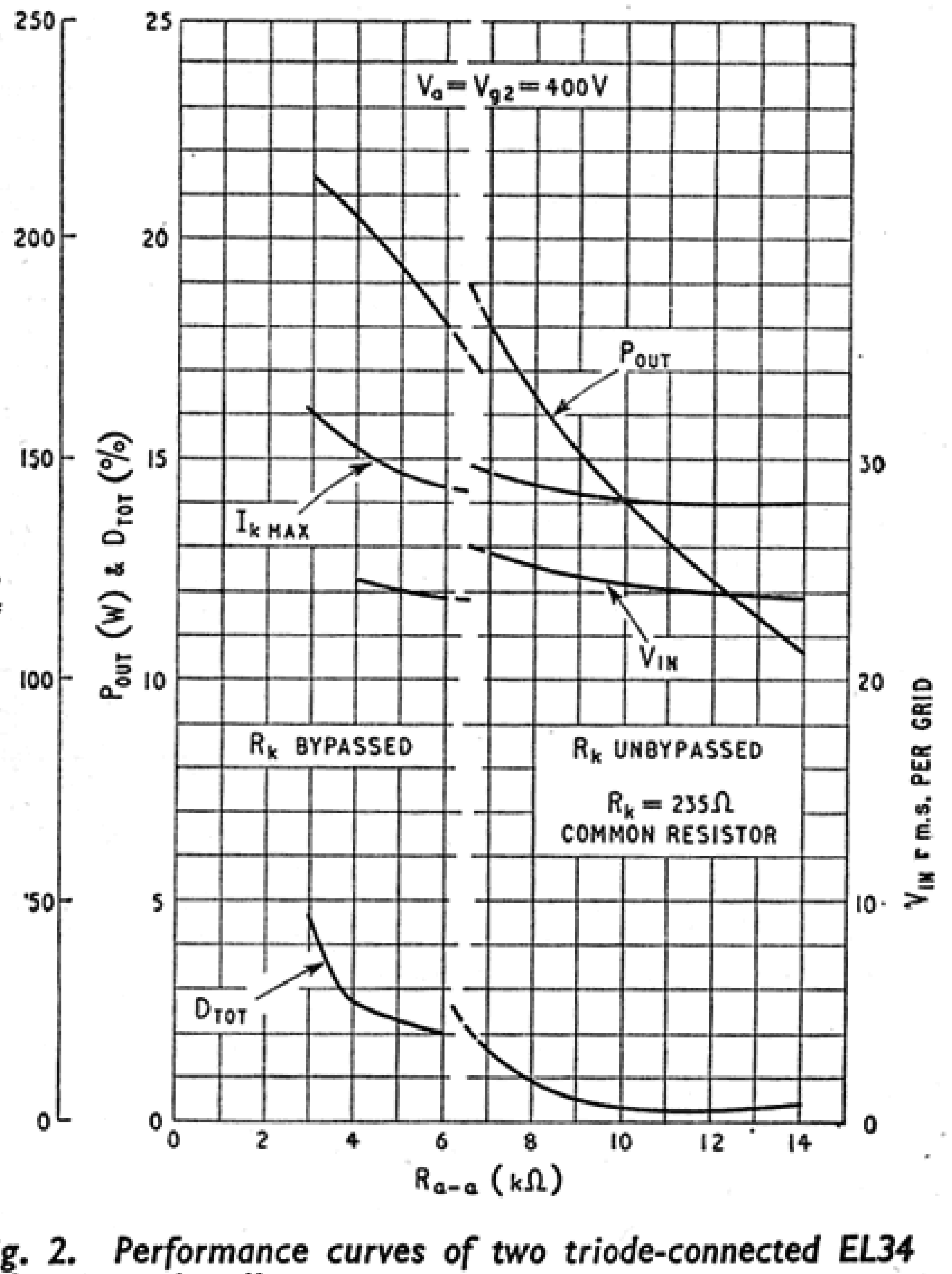

*Fig. 2. Performance curves of two triode-connected EL34 valves in push-pull.*

applied in a non-linear manner via the screen grids. The characteristics of the distributed load stage are intermediate between those for pentode and triode operation, approaching triode operation as the percentage of the primary winding common to anode and screen-grid circuits increases. It is found that under optimum conditions about two-thirds of the power-handling capacity of the corresponding pentode stage can be realized with much reduced distortion, whilst at power levels corresponding to triode operation, a similar order of distortion is obtained. At the same time the output impedance is reduced to a level approaching that obtained when a conventional push-pull triode stage is used.

Such a stage can thus be used with pentodes of the 25-watt class in high-quality amplifiers designed for power outputs well in excess of 15 watts, the overall power efficiency being appreciably greater than with triode operation. Conversely, the performance of 12-watt pentodes can be improved appreciably, although the power-handling capacity is somewhat reduced. However, effective power outputs of 10-12 watts can still be obtained.

A comparison is given in Table 1 of triode, pentode and distributed load operation for the Mullard EL34 and EL84 output pentodes. For valves of the EL34 type, comparison with triode operation is of most interest. It will be seen that distributed-load operation using a tapped primary output transformer enables the power-handling capacity to be more than double that possible with triode operation, whilst at the same time distortion in the stage can be held to a very low level.

Although with a common winding ratio of 0.2, i.e., with 20% of the primary winding common to anode and screen-grid circuits, the distortion level is comparable with triode conditions, it has been found that appreciable improvement is obtained at higher power outputs if the common winding ratio is further increased. Progressive improvement in overall performance has been obtained with the percentage of common primary winding increased up to 40-45%. Although with this increase power-handling capacity is still further reduced, at least 35 watts output can be obtained with distortion at the onset of grid current at about 2.5%.

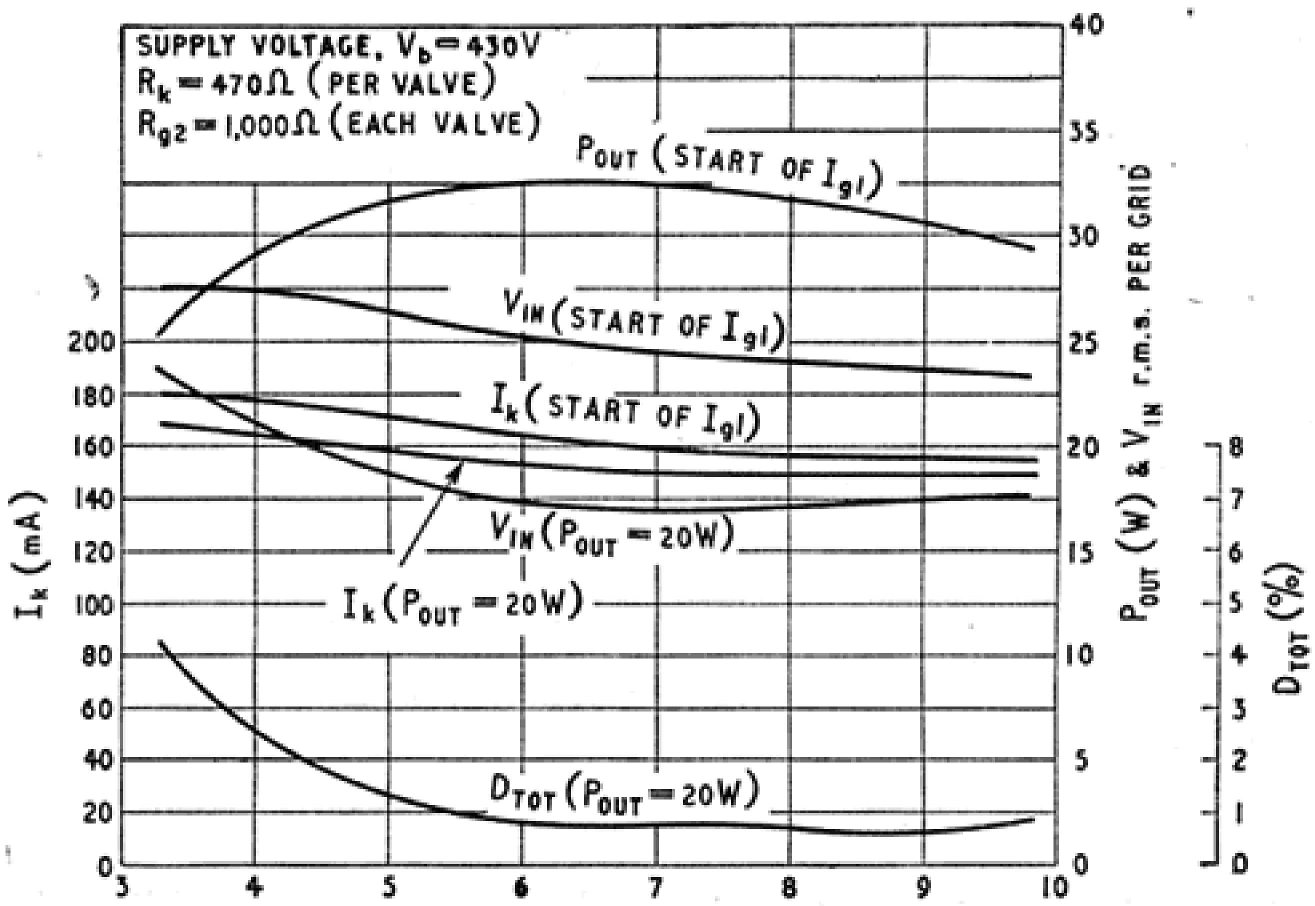

*Fig. 3. Performance of EL34 push-pull pentodes under distributed-load conditions with screen tappings at 43% of primary turns.*

Performance typical of the EL34 when used with an output transformer having a primary winding tapped at 43% of the turns is shown in Fig. 3. The output transformer used for these measurements was the Partridge type UL2 and the values of power out-

**TABLE 1**

| Valve type | Mode of operation | Operating conditions | | | | | Total distortion (per cent) | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $V_a$ (V) | $V_{g2}$ (V) | $R_k$ (Ω) | $R_{a-a}$ (kΩ) | $R_{g2}$ (Ω) | at10W | 14W | 20W | 30W |
| Mullard EL34 | Triode connection .. | 400 | * | 470 (per valve) | 10 | * | 0.5 | 0.7 | — | — |
| | Distributed load: 43% common winding | 400 | 400 | 470 (per valve) | 6.6 | 1000 (per valve) | 0.6 | 0.7 | 0.8 | 1.0 |
| | Pentode connection .. | 330 | 330 | 130 (common) | 3.4 | 470 (common) | 1.5 | 2.0 | 2.5 | 4.0 |
| | | | | | | | at 5W | 10W | 15W | |
| Mullard EL84 | Triode connection .. | 300 | * | 150 (common) | 10 | * | 1.0 | — | — | |
| | Distributed load: 20% common winding | 300 | 300 | 270 (per valve) | 6.6 | — | 0.8 | 1.0 | 1.5† | |
| | 43% common winding | 300 | 300 | 270 (per valve) | 8.0 | — | 0.7 | 0.9 | — | |
| | Pentode connection .. | 300 | 300 | 270 (per valve) | 8.0 | — | 1.5 | 2.0 | 2.0 | |

*Screen grid strapped to anode.

†See text.

put quoted are those delivered to the load in the secondary circuit.

With valves of the 12-watt dissipation class, such as the EL84, comparison with normal pentode operation is more significant. Appreciable reduction in odd harmonic distortion is again obtained under distributed load conditions and approximately 15 watts is delivered by the valves with a common winding ratio of 0.2.

From the figures in Table 1, little advantage would appear to be gained by further approaching triode conditions. There are, however, at least two advantages in using a tap at about 40% of primary turns, particularly with the EL34 where a high power output is still available. In the first place almost identical performance is obtained under cathode- and fixed-bias conditions, since with the closer approach to Class A triode working, variations in anode and screen-grid currents are reduced when the stage is driven. Secondly, as with normal triode operation, power output and distortion are less dependent on the precise value of load impedance. With a primary tap at about 40% of turns little change in performance is produced by a change in anode-to-anode load impedance of 6,000 to 9,000Ω. In addition the output impedance of the stage is still further reduced by the use of the larger common winding ratio.

**Circuit Arrangements.**—The penultimate stage of the amplifier must be capable of providing a well-balanced push-pull drive of adequate amplitude and low distortion content. With 25-watt pentodes such as the EL34 the maximum drive voltage required is approximately 2 × 25 volts r.m.s., whilst for valves of the EL84 type the corresponding input is about 2 × 10 volts r.m.s. Input voltage requirements are similar for triode, pentode or distributed-load operation.

Bearing in mind the need to ensure stability when feedback is applied over the whole amplifier, the circuit should contain the minimum number of stages, in order to reduce phase shifts to the minimum. Thus if the functions of phase splitting and amplification can be combined in the penultimate stage, so much the better. This can be conveniently achieved by using the cathode-coupled form of phase splitter[5]. A high degree of balance is possible with this circuit, combined with a low distortion level at maximum drive to the output stage. By using a high-impedance double triode, an effective stage gain of about 25 times can be simultaneously obtained. This, combined with a preceding high-gain stage, enables a high overall sensitivity to be obtained, even when a high degree of negative feedback is used. A high sensitivity in the main amplifier enables the output voltage requirements of pre-amplifier and tone control circuits to be reduced; low distortion in these circuits is then more easily obtained.

It should be remembered in this connection that circuits preceding the main amplifier must be capable of handling, without appreciable distortion, voltages much greater than are necessary to load the amplifier fully.

With the use of such a valve as the Mullard EF86, which is particularly suitable for use in a high-sensitivity input stage, due to its low hum and noise levels, it is found that when feedback is applied input sensitivities of 50 to 100 mV for rated output can be achieved whilst at the same time hum and noise levels are low enough for high-quality requirements.

**Negative Feedback.**—In an amplifier employing single-loop feedback from output to input, instability will occur if the loop gain—the product of amplifier gain without feedback and the attenuation of the feedback network—exceeds unity at frequencies for which the total phase shift round the loop becomes either 0 or 360° and so renders the feedback signal in phase with the input. The conditions for negative feedback imply a phase change of 180°, so that instability is approached as the additional phase shift in the amplifier and feedback network approaches 180 degrees[6].

Since phase shifts are often difficult to measure, it is normal practice to utilize for design purposes the relationship between phase shift and attenuation characteristics. A simple CR low or high pass filter produces an ultimate phase shift of 90° and a rate of attenuation which approaches 6db/octave asymptotically. Thus an ultimate phase shift of 180° corresponds to a final rate of attenuation of 12db/octave. To preserve adequate margins of stability it is usual to design for attenuation rates not exceeding 10db/octave in the region where the loop gain varies from say 10db through unity gain (0db) to −10db.

It is thus necessary to control the amplifier characteristics over a frequency range much in excess of the designed working band. As the degree of feedback increases, this control becomes more difficult and is usually limited by the leakage inductance, self-capacitance and primary inductance of the output transformer.

It is a formidable task in practice to provide a constant and high level of feedback over the whole audible frequency range in a 3- or 4-stage amplifier where the main feedback loop includes the whole circuit and the output transformer. An adequate margin of stability in such circumstances is very difficult to obtain. Thus it is more usual to find that the effective feedback decreases towards the upper and lower audible frequencies.

Adequate feedback must, however, be available:

1. At frequencies in the region of the fundamental resonance of the loudspeaker system, to provide the low output impedance needed for efficient electrical damping.

2. Up to the highest audible frequency for which harmonics lie within the audible range, a frequency which can be taken as around 10 kc/s.

**Output Transformer.**—The performance of a high-quality amplifier is ultimately dependent on the quality of the output transformer. The use of distributed-load conditions does not modify the essential features of a first-class component—on the contrary the output transformer may be a more critical component, since precise balance of primary windings must be maintained.

The requirements in a very high-quality design are well known and have been previously described in some detail[1]; it is not, therefore, proposed to do more than refer briefly to them. It may be said that the better the compromise effected between the requirements of high primary inductance, low leakage inductance and self-capacity, generous core size and low winding resistances, judged solely from the viewpoint of performance, the more expensive is the output transformer. This is particularly so if it is designed to handle power outputs in excess of 15 watts.

Whilst the best performance necessitates a costly component, it is possible to achieve, in amplifiers of

10-12 watts power output, a suitable compromise which results in a very high standard of amplifier performance with a transformer of moderate cost. A low value of leakage inductance is, for example, obtained more easily if the shunt inductance requirements are lessened, and appreciable negative feedback can then be used to offset the increased distortion at low frequencies due to lower primary inductance, reduced core size and less expensive core material.

**Summary.**—When the power handling capacity of a high-quality amplifier is not designed to exceed 10-12 watts it is possible to achieve extremely high performance with 12-watt pentodes or tetrodes. Such advantages as are possessed by 25-watt valves strapped as triodes are offset by a negligible increase in power reserve and the need for a larger and more expensive power supply.

The introduction of distributed load operation, using valves of the 25-watt class permits the design of efficient high-quality amplifiers with power-handling capacities up to 30-35 watts. Whilst it is very doubtful if such a power reserve is necessary for domestic sound reproduction—it necessitates in any case a loudspeaker system capable of handling such peak powers—amplifiers of this description find application where larger audiences are present.

It should always be remembered that the performance required of a high-quality amplifier must be judged in relation to the quality of the equipment with which it is to be used. If the use of a high-quality amplifier meriting the term is to be really justified, the pickup, pre-amplifier circuits and the loudspeaker system must themselves have a very high standard of performance.

The use of high-grade equipment in association with the power amplifier is implied in the design for the 20-watt amplifier using Mullard EL34 output pentodes under distributed load conditions, which it is hoped to describe in a subsequent article.

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[1] "Design for a High Quality Amplifier," by D. T. N. Williamson. *Wireless World*, April, 1947.

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[3] "Inexpensive 10-watt amplifier," *Wireless World*, August, 1954.

[4] "A High-quality Ten Watt Audio Amplifier," by D. H. W. Busby and W. A. Ferguson. *Mullard Technical Communications*. Vol. 1, No. 9. Nov., 1954.

[5] "Push-pull Input Circuits, Part 5," by W. T. Cocking. *Wireless World*, May, 1948.

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## PART 2

## *Constructional Details and Performance*

IN the first part of this article some considerations were discussed which affect the choice of valves and circuit arrangements in the output stages of amplifiers designed for use in high-quality sound reproduction.

In amplifiers designed to handle power outputs greater than 12 to 15 watts and in which low-distortion operation towards peak power output is still required, the use of distributed load operation with valves of the 25-watt anode dissipation class is of particular interest. By using this method of valve loading the effective power output of a low-distortion triode push-pull stage (approximately 12 watts) can be raised to 30 to 35 watts whilst the benefits of low inherent distortion and relatively low output impedance are well maintained. Performance typical of the Mullard EL34 output pentode with partial screen-grid loading was illustrated in Fig. 3 of the previous article.

The present article describes a design for a high-quality amplifier of 20 watts rated output in which similar load conditions are used for the EL34 valves in the output stage. The amplifier is intended to allow of the highest standard of sound reproduction when used in association with suitable pre-amplifier circuits, high-grade pickups and loudspeaker systems. A summary of the overall performance of the amplifier is given in Table 1.

A circuit diagram and list of component values is given in Fig. 1. The circuit arrangement is basically similar, except for the output stage, to that used in the Mullard 5-valve 10-watt high-quality amplifier design in that the output stage is driven from a cathode-coupled twin-triode phase-splitting amplifier which is in turn preceded by a high-gain voltage amplifier stage. The first stage in the amplifier is d.c. coupled to the phase splitter in order to minimize low-frequency phase shifts. The main feedback loop includes the whole circuit, the feedback voltage being derived from the secondary of the output transformer and injected in the cathode circuit of the first stage.

**Output Stage.**—The main feature of interest in the output stage is the use of the Mullard EL34 high-slope output pentode with partial screen-grid loading, the screen grids being fed from taps on the primary

**TABLE I**

**Summary of Performance of Prototype Amplifier**

**Power output:**
20 watts minimum from 30 c/s-20 kc/s.

**Power response:**
within 0.5 db of 1 kc/s level at 20 watts over range 30 c/s-20 kc/s.

**Frequency response** (1 watt level):
within 1 db of 1 kc/s level 2 c/s-100 kc/s.

**Harmonic distortion** (400 c/s):
<0.05% at 20 watts.

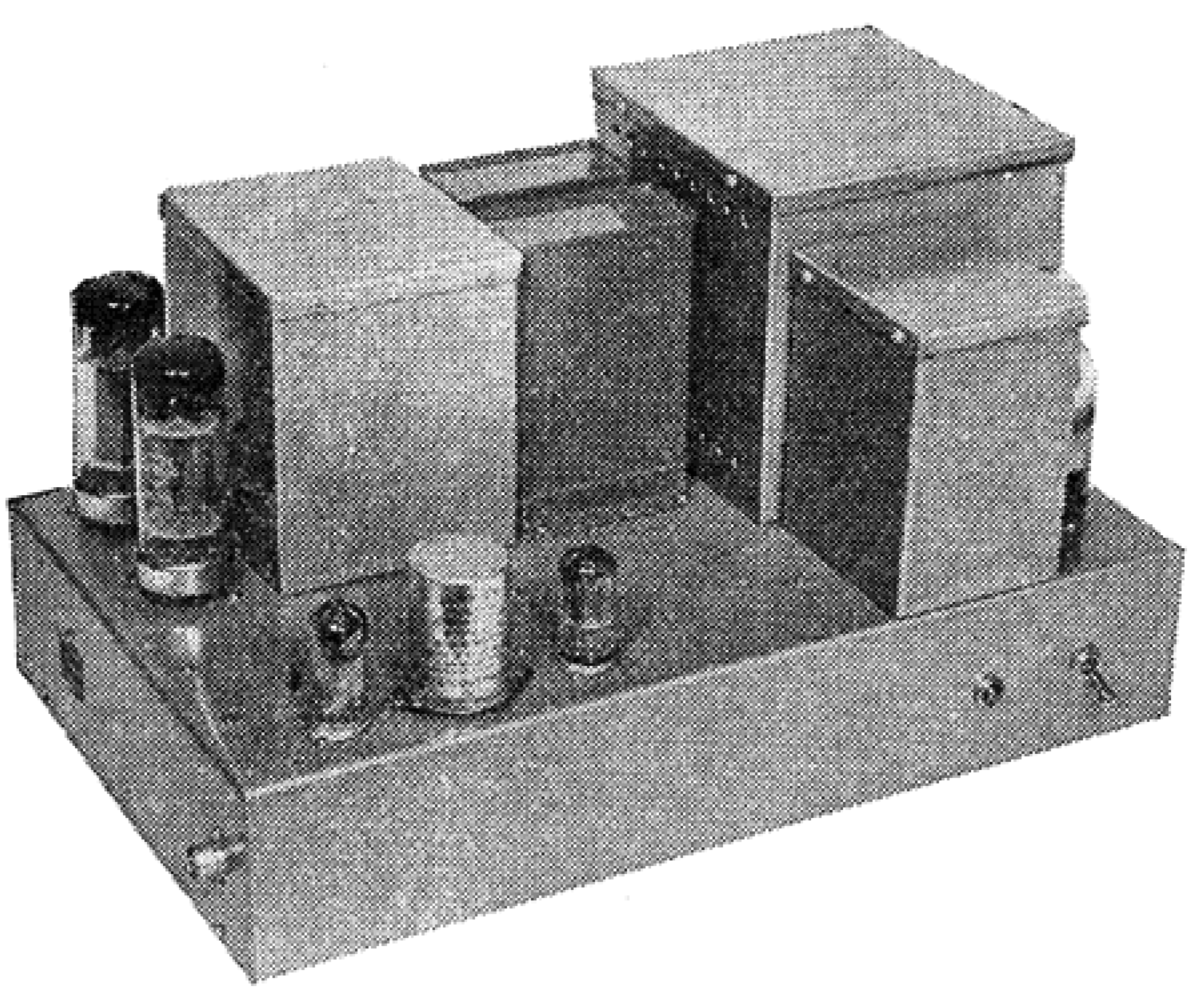
**Intermodulation distortion** (40 c/s, 10 kc/s; ratio 4:1):
0.7%, with peak corresponding to 20 W sine-wave power.
1.0%, with peak corresponding to 29 W sine-wave power.

**Hum and noise:**
−89 db relative to 20 W with 10-kΩ source resistance.

**Sensitivity:**
220 mV for 20 W output.

**Phase shift:**
10° maximum at 10 c/s.
20° maximum at 20 kc/s.

**Output impedance:**
approximately 0.3 Ω at 40 c/s, 1 kc/s and 20 kc/s at 20 watts output.

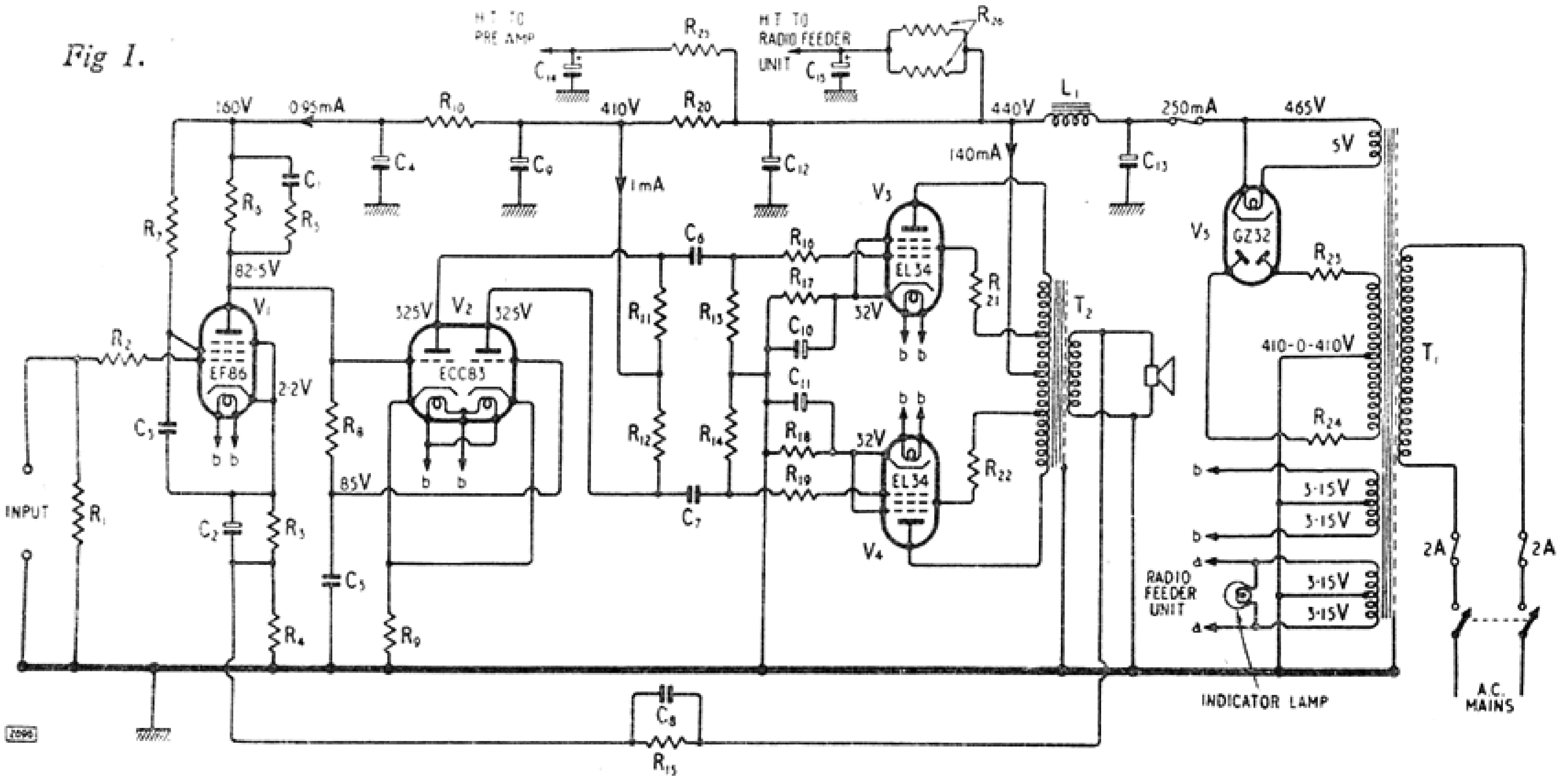


*General view of top of prototype 20-watt amplifier, which uses EL34 output valves.*

of the output transformer. Measurements during the course of design showed that optimum conditions are obtained in this form of output stage when about 40% of the primary winding of the output transformer is common to anode and screen grid circuits. In the present design a C-core transformer is used which has tappings at 43% of primary turns.

The anode-to-anode loading of the output stage is 6.6 kΩ and, with a feed voltage of 440 at the centre-tap of the output transformer primary the combined anode and screen-grid dissipation of the output valves is 28 watts per valve. With the particular screen-grid to anode load ratio used, it has been found that improved linearity is obtained at power levels above 15 watts when resistors of the order of 1,000Ω are inserted in the screen-grid feeds. The slight reduction in peak power-handling capacity which results is not significant in practice. Separate cathode-bias resistors are used to limit the out-of-balance d.c. current in the output transformer primary; the use of further d.c. balancing arrangements in the output stage has not been considered necessary. It is likely, however, that some improvement in performance, particularly at low frequencies, would result from the use of d.c. balancing. It is necessary in this type of output stage that the cathodes are bypassed to earth even when a common cathode resistor is used. Thus a low-frequency time-constant in the cathode circuit cannot be eliminated when automatic bias is used.

*Fig 1.*



## LIST OF COMPONENT VALUES

| | | |
|---|---|---|
| $R_1$ | 1 MΩ ¼ watt | ±20% |
| $R_2$ | 4.7 kΩ ¼ watt | ±20% |
| $R_3$ | 2.2 kΩ* | ±10% |
| $R_4$ | 100Ω* | ±5% |
| $R_5$ | 4.7 kΩ ¼ watt | ±10% |
| $R_6$ | 100 kΩ* | ±10% |
| $R_7$ | 390 kΩ* | ±10% |
| $R_8$ | 1.0 MΩ ¼ watt | ±20% |
| $R_9$ | 82 kΩ ½ watt | ±10% |
| $R_{10}$ | 270 kΩ ½ watt | ±10% |
| $R_{11}$ | 180 kΩ† ½ watt | ±10% |
| $R_{12}$ | 180 kΩ† ½ watt | ±10% |
| $R_{13}$ | 470 kΩ‡ ¼ watt | ±10% |
| $R_{14}$ | 470 kΩ‡ ¼ watt | ±10% |
| $R_{15}$ | 8.2 kΩ* (15-Ω load) | ±5% |
| $R_{16}$ | 2.2 kΩ ¼ watt | ±20% |
| $R_{17}$ | 470Ω 3 W min | ±5% |
| $R_{18}$ | 470Ω 3 W min | ±5% |
| $R_{19}$ | 2.2 kΩ ¼ watt | ±20% |
| $R_{20}$ | 15 kΩ ½ watt | ±20% |
| $R_{21}$ | 1 kΩ ½ watt | ±10% |
| $R_{22}$ | 1 kΩ ½ watt | ±10% |
| $R_{23}$<br>$R_{24}$ | May be required for voltage control depending on mains transformer. | |
| $R_{25}$ | 56 kΩ 1 watt | ±10% |
| $R_{26}$ | =6 kΩ made of two 12 kΩ 6 watt resistors in parallel | ±20% |
| $C_1$ | 47 pF | ±10% |
| $C_2$ | 50 μF 12 V wkg. | |
| $C_3$ | 0.05 μF 350 V wkg. | |
| $C_4$ | 8 μF 450 V wkg. | |
| $C_5$ | 0.25 μF 350 V wkg. | |
| $C_6$ | 0.5 μF 350 V wkg. | |
| $C_7$ | 0.5 μF 350 V wkg. | |
| $C_8$ | 220 pF (15-Ω load)<br>($C_8 R_{15} = 1.8\ \mu$ sec) | |
| $C_9$ | 8 μF 450 V wkg. | |
| $C_{10}$ | 50 μF 50 V wkg. | |
| $C_{11}$ | 50 μF 50 V wkg. | |
| $C_{12}$ | 8 μF 500 V wkg. | |
| $C_{13}$ | 8 μF 500 V wkg. | |
| $C_{14}$ | 8 μF 500 V wkg. | |
| $C_{15}$ | 16 μF 450 V wkg. | |
| $L_1$ | 10 H, 180 mA, 200 Ω | |
| $T_1$ | Power transformer Secondary 410-0-410V, 180 mA; 5 V, 3A; 6.3 V, 4 A centre-tapped; 6.3 V 2.5 A centre-tapped. | |
| $T_2$ | Partridge Type P3878 | |
| $V_1$ | Mullard EF86 | |
| $V_2$ | Mullard ECC83 | |
| $V_3$, $V_4$ | Mullard EL34 | |
| $V_5$ | Mullard GZ32 | |

* High-stability carbon. † Matched within 5%. $R_{12} > R_{11}$. ‡ Preferably matched within 5%.

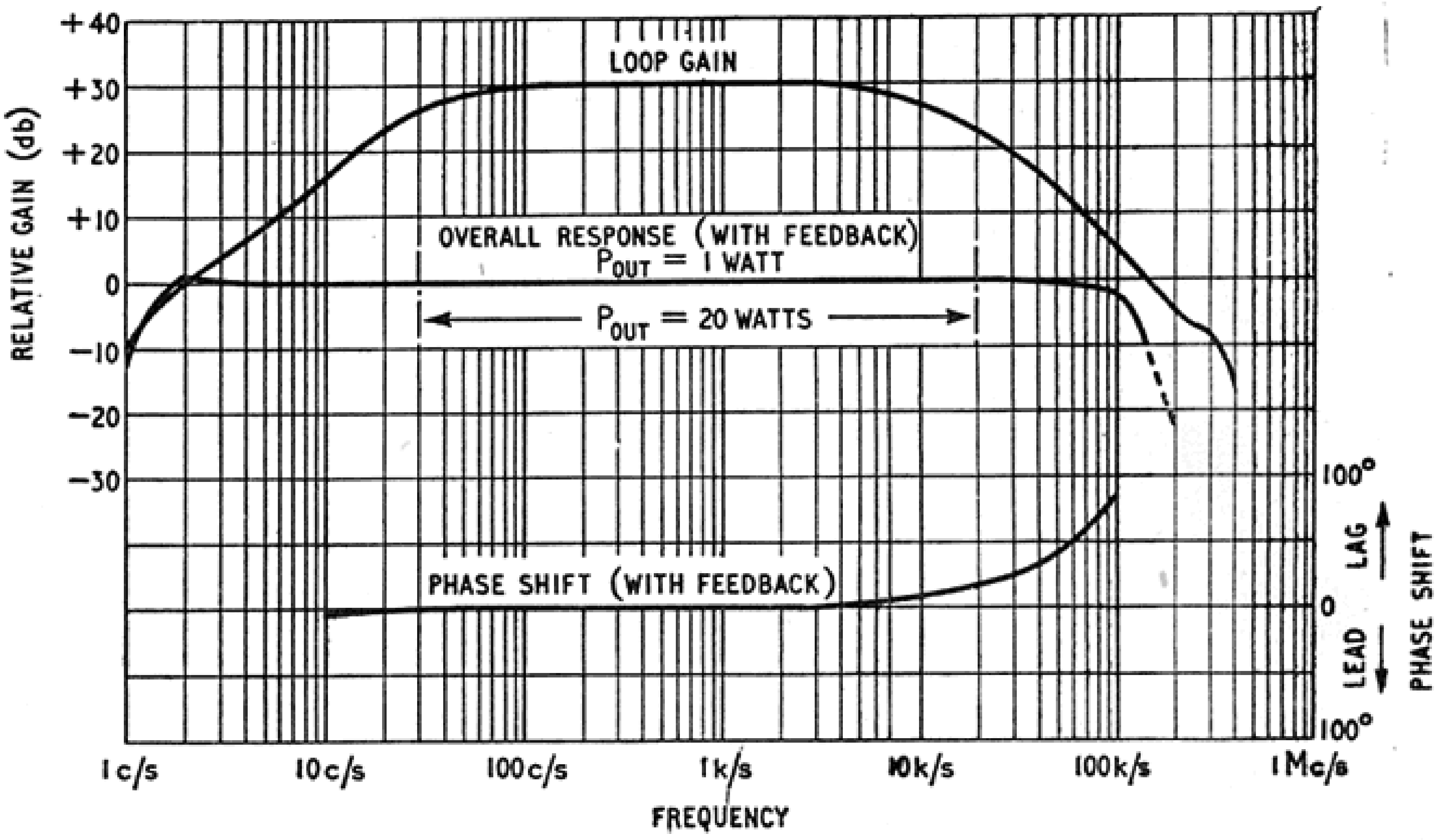


*Fig. 2. Loop gain and frequency response and phase shift characteristics with feedback.*

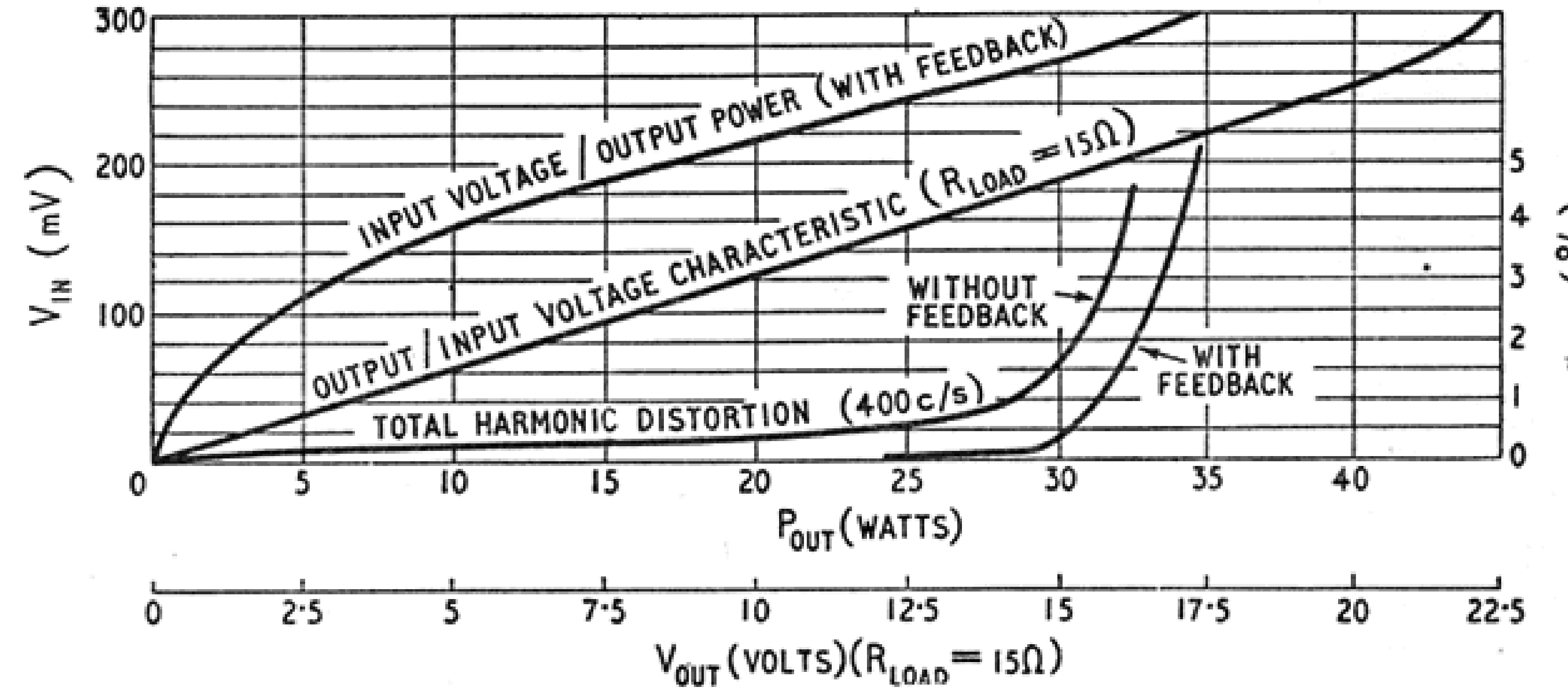


*Fig. 3. Harmonic distortion and input/output characteristics of prototype amplifier.*

**Power Supply.** — The power supply is conventional and uses a Mullard GZ32 indirectly heated full-wave rectifier in conjunction with a capacitor input filter. Paper smoothing capacitors have been used in the prototype amplifier, though the alternative use of electrolytic capacitors is possible. The value of the limiting resistors $R_{23}$ and $R_{24}$ will depend on the winding resistances of the mains transformers used. Their purpose, when required, is normally one of voltage control only. Where a transformer having very low winding resistance is used, a secondary voltage rated at 400-0-400 may be found adequate.

The rating of the mains transformer is such that an additional 30 mA may be drawn from the h.t. supply to feed pre-amplifier circuits and radio feeder. Additional decoupling will be required for these supplies.

**Driver Stage.**—This stage uses a Mullard ECC83 twin-triode and fulfils the combined function of phase splitter and driver amplifier. It is of the cathode-coupled form and enables a high degree of push-pull balance to be obtained. With the high line voltage available the required drive voltage for the output stage is obtained at a low distortion level, which is approximately 0.4% for 20 watts power output. The anode load resistors $R_{11}$ and $R_{12}$ must be matched within 5%, $R_{12}$ having the higher value for optimum operation. Optimum balance is obtained when the effective anode loads differ by 3%. It is necessary also that the grid resistors $R_{13}$ and $R_{14}$ in the output stage are of small tolerance since they form part of the anode loads of the driver stage. High-frequency balance will be largely determined by wiring layout since equality of shunt capacitances is required. Low-frequency balance is controlled by the value of the time constant $R_8$ $C_5$ in the grid circuits and this value has been chosen to ensure adequate balance down to very low frequencies. A disadvantage of the cathode-coupled form of phase splitter is that the effective voltage gain is about one-half of that obtained from one section used as a normal voltage amplifier. Due to the high $\mu$ of the ECC83 (100) the effective stage gain in the circuit is still about 25 times.

**First Stage.**—This stage is a high-gain pentode voltage amplifier using the Mullard EF86 low-hum pentode. The stage gain is approximately 120. High-stability cracked-carbon resistors are used in anode, screen-grid and cathode circuits and give appreciable improvement in measured background noise level as compared with ordinary carbon resistors. This stage is d.c. coupled to the input grid of the phase splitter in order to minimize low-frequency phase shift in the amplifier and improve low-frequency stability when feedback is applied.

**Negative Feedback.**—The sensitivity of the amplifier without feedback is 6.5 mV for 20 watts output. With feedback approximately 220 mV is required for the same output level, the designed overall loop gain being 30 db. The loop gain, overall frequency response and phase shift characteristics of the complete amplifier are shown in Fig. 2.

In spite of the high degree of negative feedback used in the present design an adequate margin of stability has been achieved. Complete stability is maintained under open-circuit conditions in the prototype amplifier. An increase in feedback of at least 10 db, obtained by reducing the value of $R_{15}$ should be possible before signs of high-frequency instability occur. In the form of design used oscillation with capacitive loads is the form of instability most likely to occur, but even with very long loudspeaker leads, instability is unlikely to arise.

**Distortion.**—The harmonic distortion of the prototype amplifier at 400 c/s, measured without feedback under resistive load conditions, is shown in Fig. 3. The distortion curve towards the overload point is also shown for feedback conditions. At the 20 watt

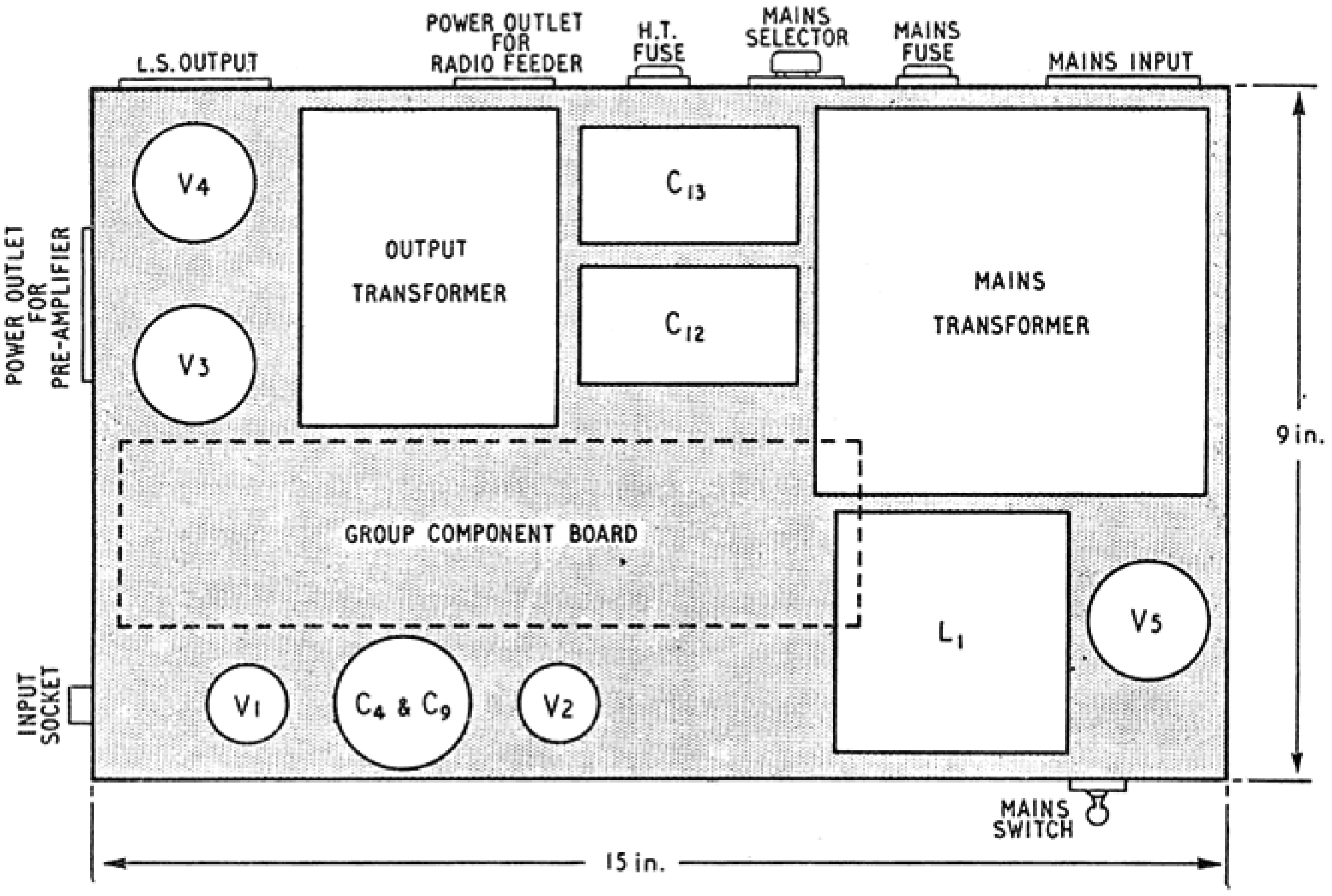


*Fig. 4. Layout of principal components in prototype amplifier.*

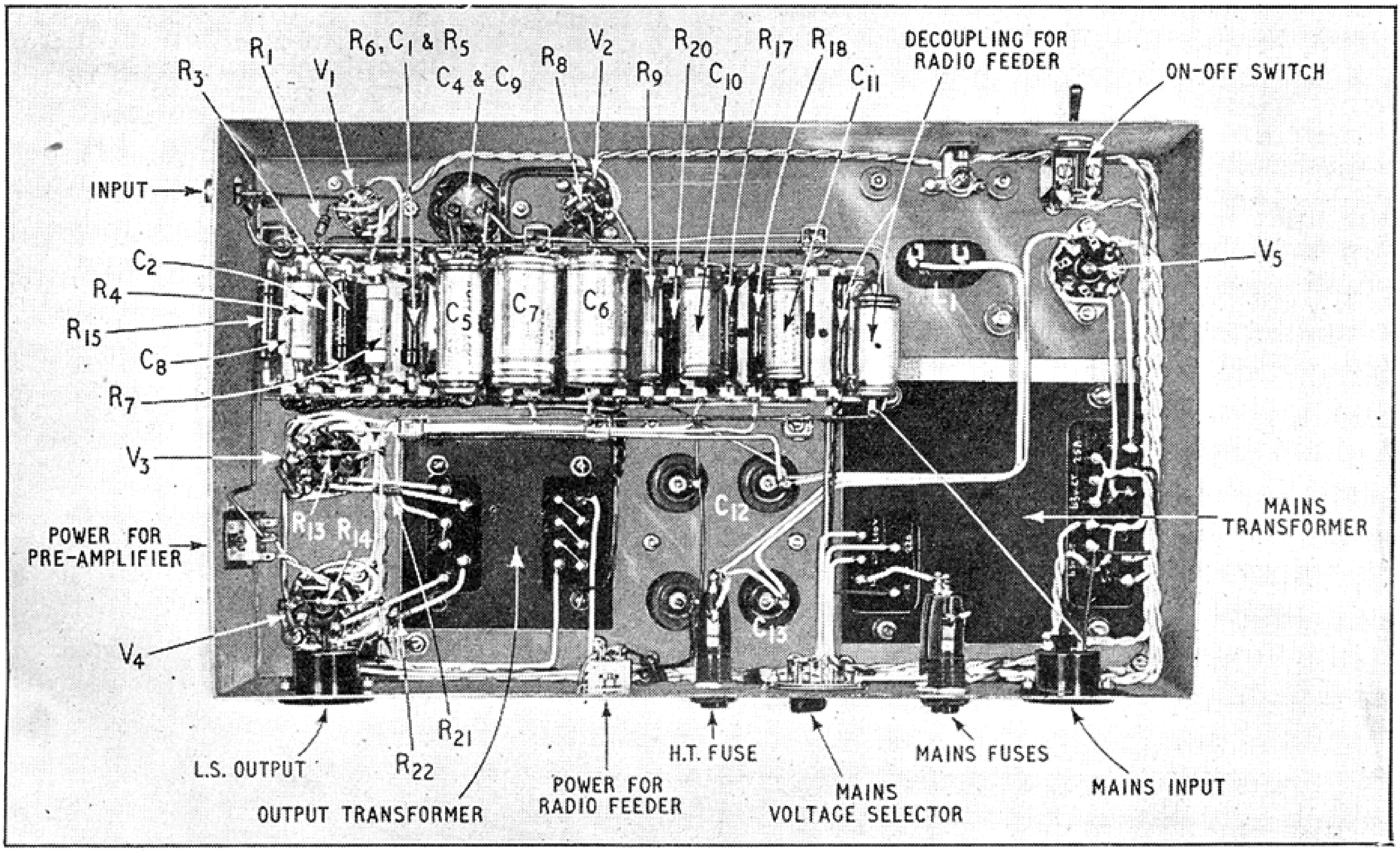
level the distortion level without feedback is well below 1% and with feedback applied falls to below 0.05%. Harmonic distortion at 400 c/s reaches 0.1% at approximately 27 watts output. The loop gain characteristics are such that at least 20 db feedback is maintained from 15 c/s to 25 kc/s and 26 db down to 30 c/s.

Measurement of intermodulation products has been made, using a carrier frequency of 10 kc/s, and a modulating frequency of 40 c/s, with a ratio of 40-c/s to 10-kc/s amplitudes of 4:1. With the combined peak amplitude of the mixed output at a level corresponding to the peak sine wave amplitude at 20 watts r.m.s. power, intermodulation products expressed in r.m.s. terms totalled 0.7% of the 10 kc/s carrier amplitude, and at 29 watts approximately 1%.

The output/input characteristic shown in Fig 3 shows that excellent linearity is obtained up to 20 volts across 15 Ω, corresponding to 27 watts output.

**Sensitivity.**—The sensitivity of the amplifier is approximately 220 mV for 20 watts output and 300 mV at the overload point at mid frequencies. The background level in the prototype amplifier was 89 db below 20 watts, measured with a source resistance of 10 kΩ. This is equivalent to about 5.5 $\mu$V at the input terminals. It is possible to increase the overall sensitivity of the amplifier by 6 db whilst still maintaining a low background level, high loop gain and a high margin of stability. However, considerations involved in the design of suitable pre-amplifier circuits, in particular the need for adequate signal-to-noise ratio, render a higher sensitivity of doubtful advantage.

**Power Response.**—It is important that adequate power-handling capacity is available at the low-



*Underside of chassis showing one possible grouping of the smaller components.*

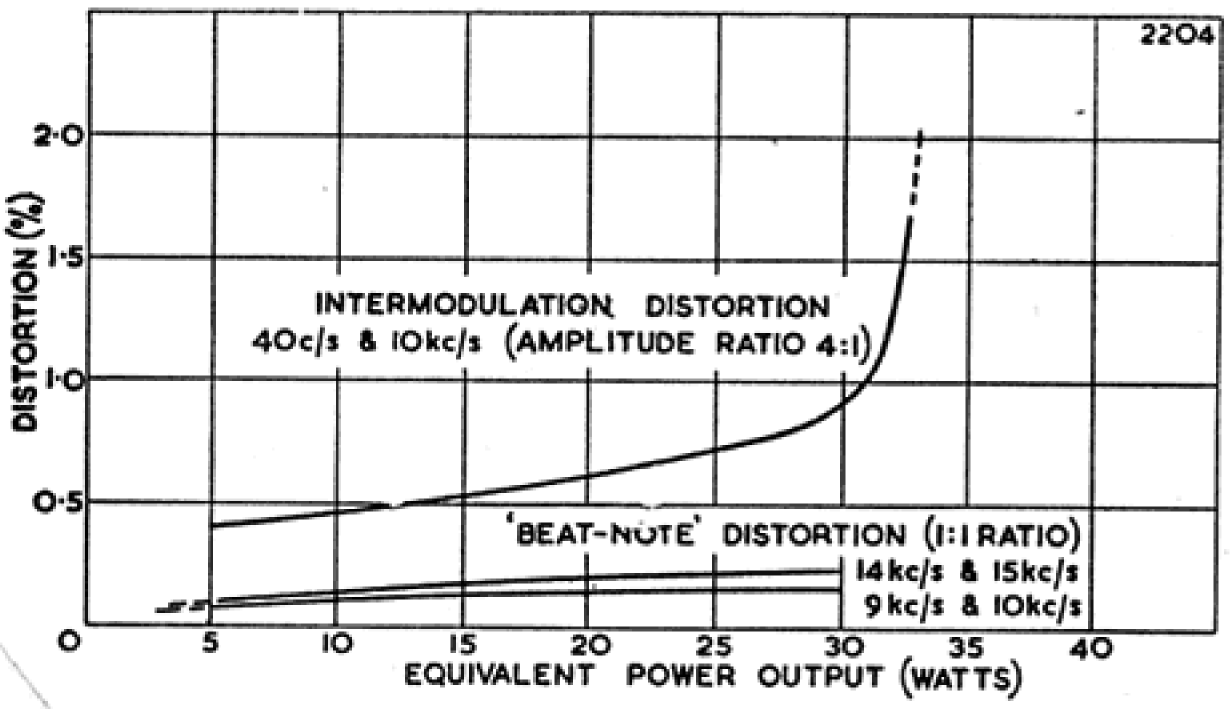
frequency end of the audible range. This is determined chiefly by the characteristics of the output transformer employed, and it is desirable that associated pre-amplifier circuits should attenuate the very low frequencies which the amplifier is incapable of handling at rated power output without excessive distortion. With the output transformer at present employed at least 20-watts capacity is available down to 30 c/s, and the frequency response at the 20-watt level is linear from 30 c/s to 20 kc/s.

**Output Impedance.**—Due to the low inherent output impedance of the output stage, combined with a high degree of negative feedback, the output impedance is very low, measuring approx. 0.3 $\Omega$ on a 15-$\Omega$ termination for 20 watts output at 40 c/s, 1 kc/s and 20 kc/s. This corresponds to a damping factor of approximately 50.

**Phase Shift and Transient Response.**—In practice a compromise must be effected between the phase shift of the amplifier, particularly at high frequencies, and the margin of stability required with a given loop gain. In the present design emphasis has been laid on ensuring as high a margin of stability as possible. The phase shift is held to a comparatively low level in the audible frequency range and, as seen from Fig. 2, reaches about 20° at 20 kc/s. Excellent response to signals of a transient nature is obtained, and the rise time of the amplifier is of the order of 5 $\mu$sec.

**Mechanical Construction.**—A diagram of the layout of the chief components as used in the prototype amplifier is shown in Fig. 4. Although this differs extensively from the layout used in the original experimental circuit no difficulty due to instability has been encountered in either arrangement. A busbar earth return has been used with chassis connection at the input socket. With minor exceptions all resistors and capacitors are mounted on group terminal boards, shown dotted on the diagram.

**GZ34 Rectifier.**—The recently introduced GZ34 rectifier can be used *in this amplifier* instead of the GZ32 originally specified with no change of base connections or mains transformer. The values of limiting resistors $R_{23}$ and $R_{24}$ which depend on the type of mains transformer must be increased. For example, with the Partridge P3878 used in the prototype amplifier $R_{23}$ and $R_{24}$ were each 82Ω. These should be increased to 100Ω when the GZ34 is fitted. With either rectifier they should be 6 W wirewound resistors.



*Intermodulation distortion and " beat note " distortion.*

**Extra Parts**

1 × Co-axial Socket. Belling Lee L734/S
1 × Elcom 6-way Socket. List No. S.06
1 × Elcom 4-way Socket. List No. S.04
1 × Bulgin 3-pin Mains Socket. List No. P340 (Main
Input)
3 × Belling Lee Fuseholders L356
1 × Mains Selector. Clix List No. CTSP/2
1 × Bulgin 2-pin Socket. List No. P350 (L.S. Output)
1 × Bulgin 2-pole Mains Switch. S300
1 × Indication Lampholder. Bulgin D180/Red
2 × 10-position Tag Boards. Bulgin. List No. C114
3 × Octal Base
1 × Noval Base (Nylon Loaded, Skirted)
1 × Noval Base (Normal)
Fuses 2 × 2 A, 1 × 250mA

### Smoothing Choke

| f1 | f2 | |
|---|---|---|
| $2\frac{5}{16}$in. | $2\frac{1}{16}$in. | Gardners C.251.A |
| $2\frac{1}{8}$in. | $1\frac{7}{8}$in. | Partridge P.3879 VDE/442B |
| $3\frac{1}{8}$in. | $2\frac{1}{16}$in. | Partridge P.3879 PMN/442B |

### Output Transformer

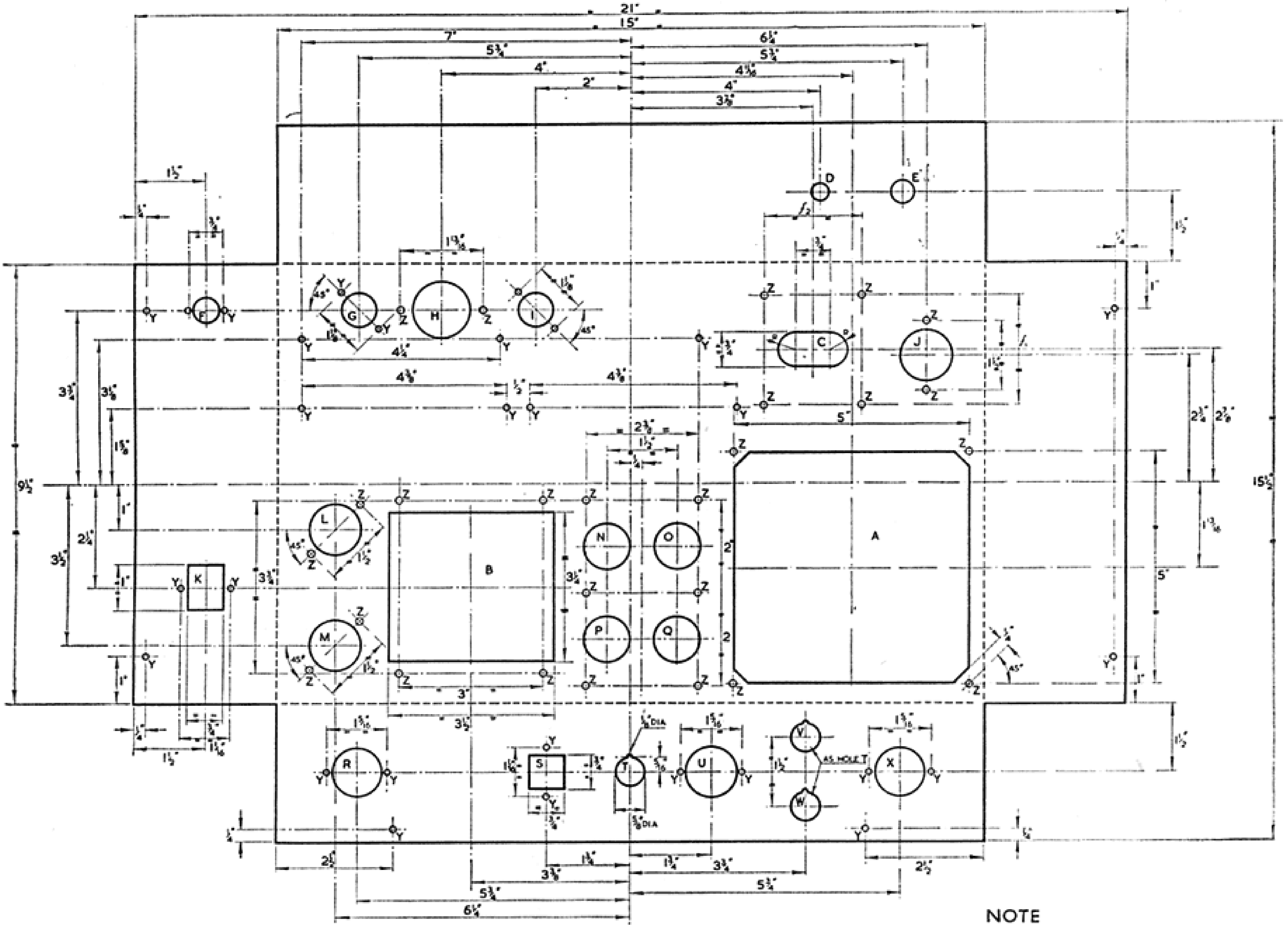
| Manufacturer | List No. | Style |
|---|---|---|
| Parmeko | P.2647 | |
| Partridge | P.3878 | Z.371107 |
| Partridge | P.3878 | Z.371062 |

### Mains Transformer

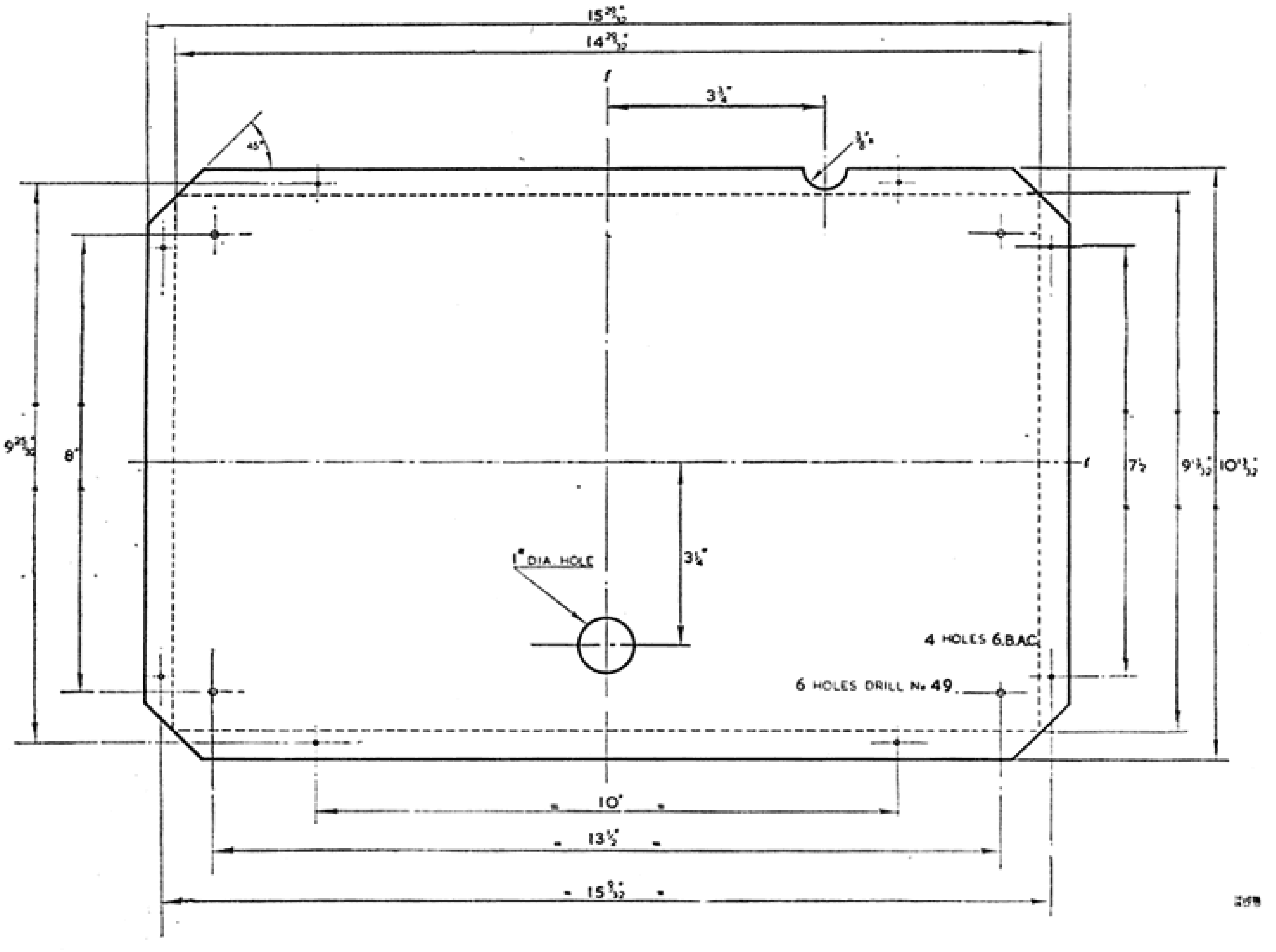
| Manufacturer | List No. | Style |
|---|---|---|
| Parmeko | P.2646 | |
| Partridge | P.3877 | DN/436B |
| Partridge | P.3877 | PMN/436B |

**Key to Holes on Chassis Drawing**

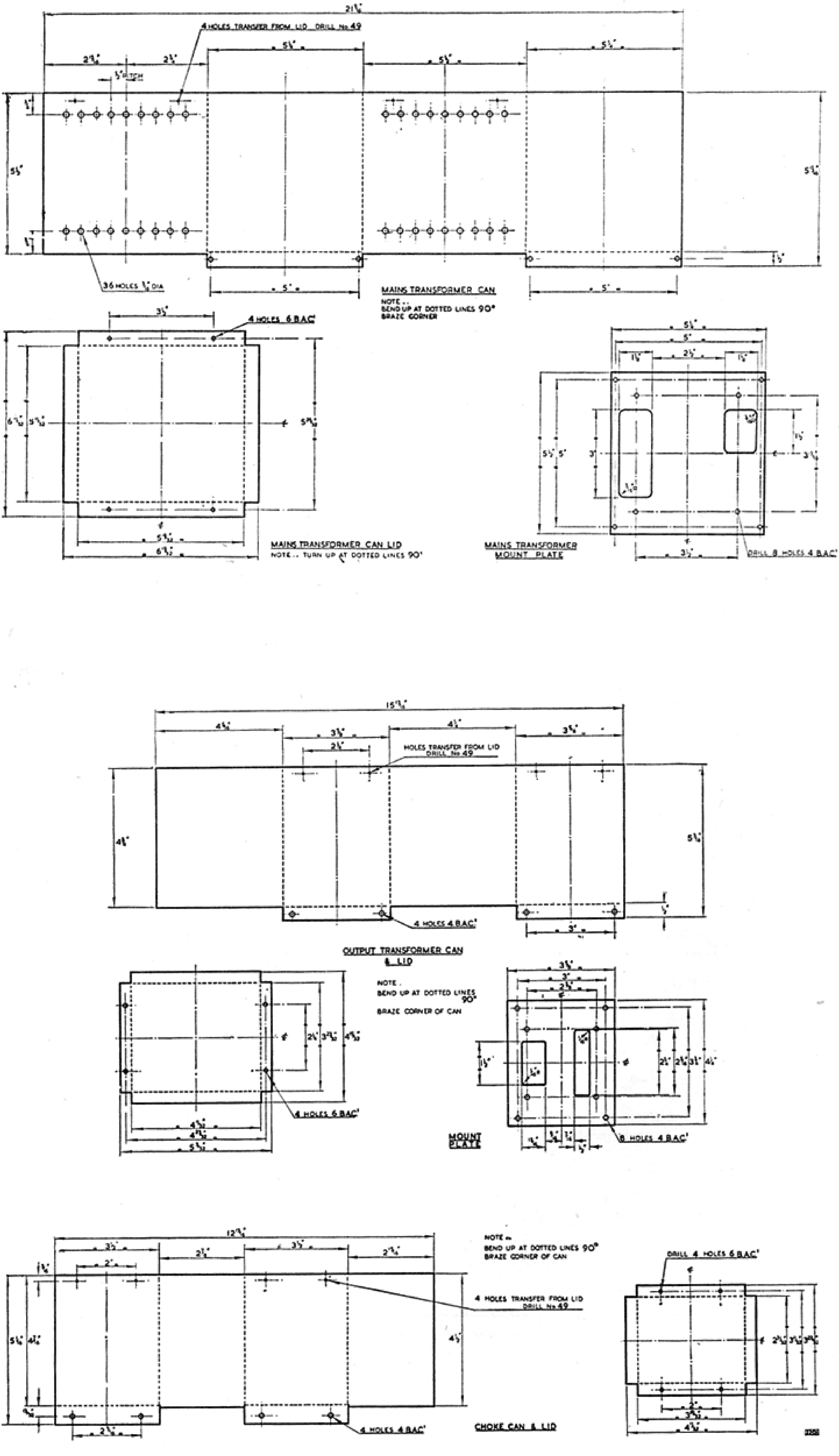
| | | |
|---|---|---|
| A | — | Mains Transformer |
| B | — | Output Transformer |
| C | — | 10 H 180 mA Choke |
| D | $\frac{3}{8}$in. | Bulgin Indicator Lamp D180/Red |
| E | $\frac{1}{2}$in. | Bulgin Mains Switch S.300 |
| F | $\frac{9}{16}$in. | Belling Lee Co-axial Socket L.734/S |
| G | $\frac{3}{4}$in. | Noval Valve Base (Nylon Loaded) |
| H | $1\frac{1}{4}$in. | Electrolytic Capacitor 50+50$\mu$F |
| I | $\frac{3}{4}$in. | Noval Valve Base (Nylon Loaded) |
| J | $1\frac{1}{8}$in. | International Octal Valve Base |
| K | — | Elcom 6-pin Socket S.06 |
| L | $1\frac{1}{8}$in. | International Octal Valve Base |
| M | $1\frac{1}{8}$in. | International Octal Valve Base |
| N | 1in. | Capacitor 8$\mu$F |
| O | 1in. | |
| P | 1in. | Capacitor 8$\mu$F |
| Q | 1in. | |
| R | $1\frac{1}{16}$in. | Bulgin 2-pin Mains Plug P.350 |
| S | — | Elcom 4-pin Socket S.04 |
| T | $\frac{5}{8}$in. | Belling Lee Fuse Holder L.356 |
| U | $1\frac{1}{8}$in. | Clix Mains Selector CTSP/2E1 |
| V | $\frac{5}{8}$in. | Belling Lee Fuse Holder L.356 |
| W | $\frac{5}{8}$in. | Belling Lee Fuse Holder L.356 |
| X | $1\frac{1}{16}$in. | Bulgin 3-pin Mains Plug P 340 |
| Y | 6 B.A.C. | |
| Z | 4 B.A.C. | |



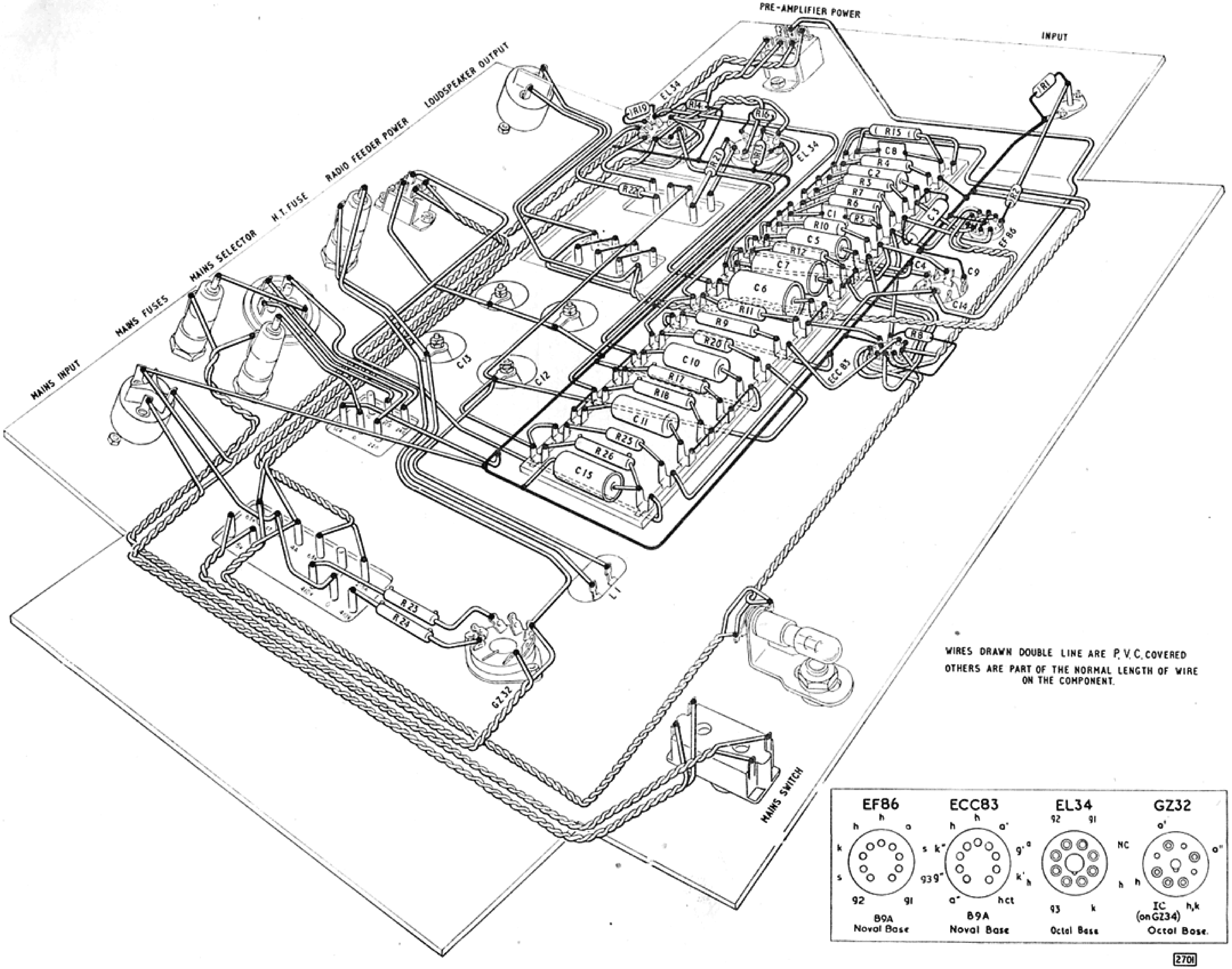
**NOTE**
Bend chassis and lid at dotted lines 90° up. Chassis material 16 S.W.G. brass or B.M.S. Braze corners of chassis.



*Main chassis drawing for the 20-watt amplifier.*



*Drawings of cans and lids for components on the 20-watt amplifier chassis.*



WIRES DRAWN DOUBLE LINE ARE P.V.C. COVERED
OTHERS ARE PART OF THE NORMAL LENGTH OF WIRE ON THE COMPONENT.

*Point-to-point wiring diagram for the 20-watt amplifier. The bus-bar is shown as a heavy line.*