CHAPTER 5

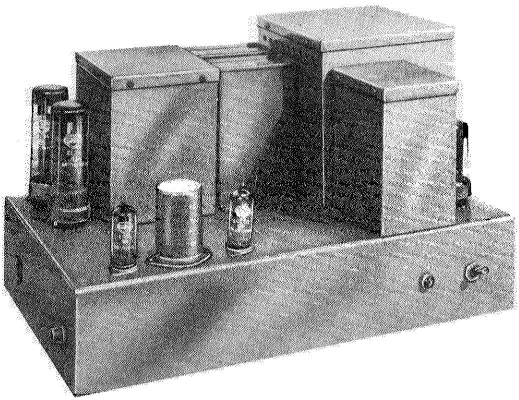
Twenty-watt Amplifier

The circuit to be described in this chapter is designed to give the highest standard of sound reproduction when used in association with a suitable pre-amplifier, a high-grade pick-up head and a good-quality loudspeaker system.

Two Mullard output pentodes, type EL34, rated at 25W anode dissipation, form the output stage of the circuit. These are connected in a push-pull arrangement with distributed loading, and give a reserve of output power of 20W with a level of harmonic distortion less than 0·05%. The intermediate stage consists of a cathode-coupled, phase-splitting amplifier using the Mullard double triode, type ECC83. This stage is preceded by a high-gain voltage amplifier incorporating the Mullard low-noise pentode, type EF86. Direct coupling is used between the voltage amplifier and phase splitter to minimise low-frequency phase shifts.

The main feedback loop includes the whole circuit, the feedback voltage being derived from the secondary winding of the output transformer and being injected in the cathode circuit of the EF86. The amount of feedback applied around the circuit is 30dB, but in spite of this high level, the stability of the circuit is good and the sensitivity is 220mV for the rated output power. The level of hum and noise is 89dB below the rated 20W.

The rectifier used in the power-supply stage is the Mullard full-wave rectifier, type GZ34. This provides sufficient current for the amplifier (about 145mA) and also for the pre-amplifier and f.m. radio tuner unit (about 40mA) being used with it.



Prototype of Mullard Twenty-watt Amplifier

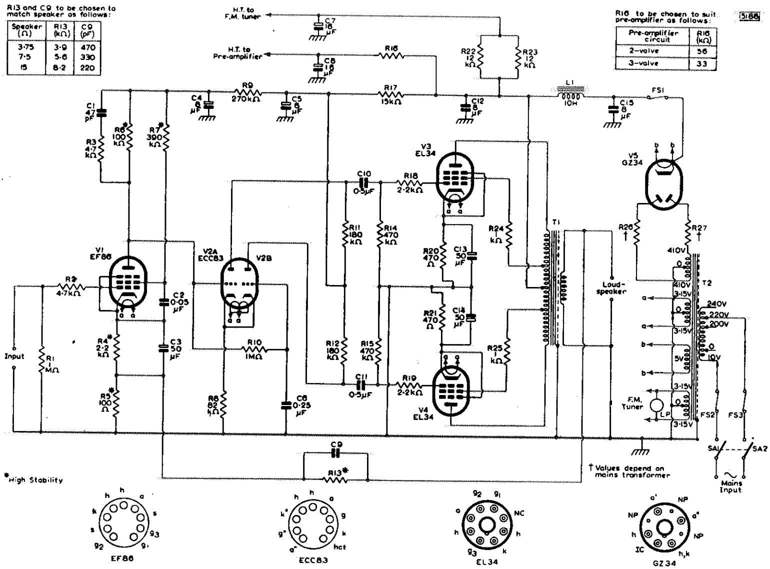


Fig. 1—Circuit diagram of 20W amplifier

CIRCUIT DESCRIPTION

Input Stage

The EF86 input stage of the circuit of Fig. 1 provides high-gain voltage amplification, the stage gain being approximately 120 times. High-stability, cracked-carbon resistors are used in the anode, screen-grid and cathode circuits, and they give an appreciable improvement in the measured level of background noise compared with ordinary carbon resistors.

The stage is coupled directly to the input of the phase splitter. The purpose of this is to minimise low-frequency phase shift in the amplifier and to improve the low-frequency stability when negative feedback is applied. A CR network (C1, R3) connected across the anode load produces an advance in phase and thus improves the high-frequency stability of the amplifier.

Intermediate Stage

The second stage of the circuit uses a Mullard double triode, type ECC83, and fulfils the combined function of phase splitter and driver amplifier. The phase splitter is a cathode-coupled circuit which enables a high degree of balance to be obtained in the push-pull drive signal applied to the output stage.

With the high line voltage available, the required drive voltage for an output power of 20W is obtained with a low level (0·4%) of distortion. The anode load resistors R11 and R12 should be matched to within 5%, R12 having the higher value for optimum operation. Optimum balance is obtained when the effective anode loads differ by 3%. The grid resistors R14 and R15 of the output stage should also be close-tolerance components because they also form part of the anode load of the driver stage. High-frequency balance will be determined largely by the wiring layout because equality of shunt capacitances is required. Low-frequency balance is controlled by the time constant C_6R_{10} in the grid circuits of the triode sections, and the time constant chosen in Fig. 1 will give 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 half that attainable with one section of the valve used as a normal voltage amplifier. However, as the mutual conductance of the ECC83 is high (100), the effective gain of the cathode-coupled circuit is still about 25 times.

LIST OF COMPONENTS

Resistors

Circuit ref.	Value	Tolerance (±%)	Rating (W)
R1	1 MΩ	20	1/4
R2	4·7kΩ	20	1/4
R3	4·7kΩ	10	1/4
[1]R4	2·2kΩ	10	1/2
[1]R5	100 Ω	5	1/2
[1]R6	100 kΩ	10	1/2
[1]R7	390 kΩ	10	1/2
R8	82 kΩ	10	1/4
R9	270 kΩ	10	1/2
R10	1 MΩ	20	1/4
[2]R11	180 kΩ	10	1/2
[2]R12	180 kΩ	10	1/2
[1]R13 for 3·75Ω speaker	3·9kΩ	5	1/2
for 7·5Ω speaker	5·6kΩ	5	1/2
for 15Ω speaker	8·2kΩ	5	1/2
[3]R14	470 kΩ	10	1/4
[3]R15	470 kΩ	10	1/4
R16 for 2-valve pre-amp.	56 kΩ	10	1
for 3-valve pre-amp.	33 kΩ	10	1
R17	15 kΩ	20	1/2
R18	2·2kΩ	20	1/4
R19	2·2kΩ	20	1/4
R20	470 Ω	5	3
R21	470 Ω	5	3
R22	12 kΩ	20	6
R23	12 kΩ	20	6
R24	1 kΩ	10	1/2
R25	1 kΩ	10	1/2
R26 and R27	Values depend on mains transformer		6

1. High stability, cracked carbon
2. Matched to within 5%
3. Preferably matched to within 5%
4. Wire wound

Capacitors

Circuit ref.	Value	Description	Rating (V)
C1	47 pF	silvered mica[5]	
C2	0·05 μF	paper	350
C3	50 μF	electrolytic	12
C4	8 μF	electrolytic	450
C5	8 μF	electrolytic	450
C6	0·25 μF	paper	350
C7	16 μF	electrolytic	450
C8	8 μF	electrolytic	500
C9 for 3·75Ω speaker	470 pF	silvered mica[6]	
for 7·5Ω speaker	330 pF	silvered mica[6]	
for 15Ω speaker	220 pF	silvered mica[6]	
C10	0·5 μF	paper	350
C11	0·5 μF	paper	350
C12	8 μF	paper	500
C13	50 μF	electrolytic	50
C14	50 μF	electrolytic	50
C15	8 μF	paper	500

5. Tolerance, ±10%
6. Tolerance, ±5%

Valves

Mullard EF86, ECC83, EL34 (two), GZ34

Valveholders

B9A (noval) nylon-loaded, with screening skirt (for EF86) McMurdo, XM9/AU, Skirt 95
B9A (noval) nylon-loaded (for ECC83), McMurdo XM9/AU
B8-O (International octal) (three, for EL34s and GZ34), McMurdo B8/U

Miscellaneous

Mains input plug, 3-way. Bulgin, P340
Mains switch, 2-pole. Bulgin, S300
Mains selector. Clix, CTSP/2
H.T. supply socket (f.m. tuner), 4-way. Elcom, S.04
H.T. supply socket (pre-amplifier), 6-way. Elcom, S.06
Fuseholders (three). Belling Lee, L356
Fuses, 2A (two); 250mA (one)
Lampholder. Bulgin, D180/Red
Pilot lamp. 6.3V, 40mA
Input socket, coaxial. Belling Lee, L.734/S
Output plug, 2-pin. Bulgin, P350
Tagboard (10-way) (two). Bulgin, C114

Output Transformer T1

Primary Impedance:
7kΩ for 20% screen-grid taps
6·6kΩ for 43% screen-grid taps

Mains Transformer T2

Primary: 10–0–200–220–240V
Secondaries: H.T., 410–0–410V, 180mA
3·15–0–3·15V, 4A
3·15–0–3·15V, 2·5A
0–5V, 3A

Smoothing Choke L1

Inductance: 10H at 180mA
Resistance: 200Ω

Commercial Components

Manufacturer	Output Transformer Type No. 20% Taps	Output Transformer Type No. 43% Taps	Mains Transformer Type No.	Choke Type No.
Colne	03070	03069	03068	03071
Elden	486A	486	477	478
Gardners	AS.7034	AS.7034	RS.3175	CS.5142
Gilson	W.O.1342	W.O.866	W.O.775	W.O.1340
			W.O.917	W.O.1341
Hinchley	1532	1377	1441	1528
Parmeko	P2913	P2647	P2646	P463
Partridge	—	P3878	P3877	C10/180
	—	P6878	P6877	—
Savage	—	4B14	4B32-1	—
Wynall	W1900C	W1552C	W1584	W1585

Output Stage

The main feature of interest in the output stage is the use of two EL34s with partial screen-grid (or distributed) loading, the screen grids being fed from tappings on the primary winding of the output transformer. As stated in Chapter 3, the best practical operating conditions are achieved with this type of output stage when about 20% of the primary winding is common to the anode and screen-grid circuit.

The anode-to-anode loading of the output stage is 7kΩ and, with a line voltage of 440V at the centre-tap of the primary winding of the output transformer, the combined anode and screen-grid dissipation of the output valves is 28W 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 15W when resistors of the order of 1kΩ are inserted in the screen-grid supply circuits. The slight reduction in peak power-handling capacity which results is not significant in practice.

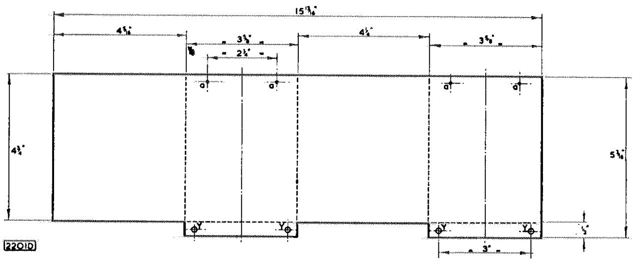
Separate cathode-biasing resistors are used in the output stage to limit the out-of-balance direct current in the primary winding of the output transformer. The use of other balancing arrangements has not been thought necessary although it is likely that some improvement in performance, particularly at low frequencies, would result from the use of d.c. balancing. It is necessary in this type of output stage for the cathodes to be bypassed to earth even if a shared cathode resistor is used. Consequently, a low-frequency time constant in the cathode circuit cannot be eliminated when automatic biasing is used.

Negative Feedback

Negative feedback is taken from the secondary winding of the output transformer to the cathode circuit of the input stage. In spite of the high level of feedback used (30dB), the circuit is completely stable under open-circuit conditions. At least 10dB more feedback (obtainable by reducing the value of R13) would be required to cause high-frequency instability. The most probable form of instability would be oscillation with capacitive loads, but this is most unlikely to occur even with very long loudspeaker leads.

Power Supply

The power supply is conventional and uses a Mullard indirectly-heated, full-wave rectifier, type GZ34, in conjunction with a capacitive input filter. The values of the limiting resistors R26 and R27 will depend on the winding resistances of the mains transformer used.



2201D

DRILL HOLES IN SCREENING CANS	
Holes	Drill Size
a	49
Y	34
Z	27

Sections of Figs. 2, 3 and 4 should be bent up at 90° at all dotted lines.

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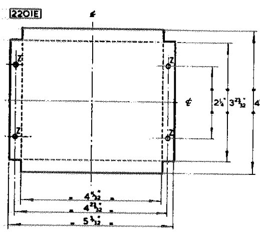
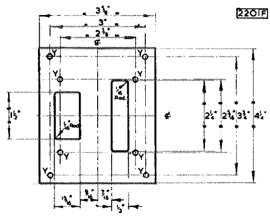




2201F

Fig. 2—Screening can for output transformer

(a) (above) Can

(b) (far left) Lid

(c) (near left) Mounting plate

Their purpose, when required, is normally one of voltage control only. Where a transformer with a very low winding resistance is used, a secondary voltage rated at 400–0–400V may be found adequate. The rating of the mains transformer is such that about 40mA may be drawn from the h.t. supply to feed a pre-amplifier circuit and f.m. tuner in addition to the normal current required (about 145mA) for the amplifier.

Extra decoupling will be need for these ancillary supplies. The smoothing components R22, R23 and C7 can only be chosen when the type of tuner to be used is known. The values given in Fig. 1 would be suitable for typical current and voltage requirements of approximately 40mA and 200V. The components R16 and C8 depend on the pre-amplifier to be used. The values given in Fig. 1 refer to the 2- and 3-valve pre-amplifiers described in Chapter 9.

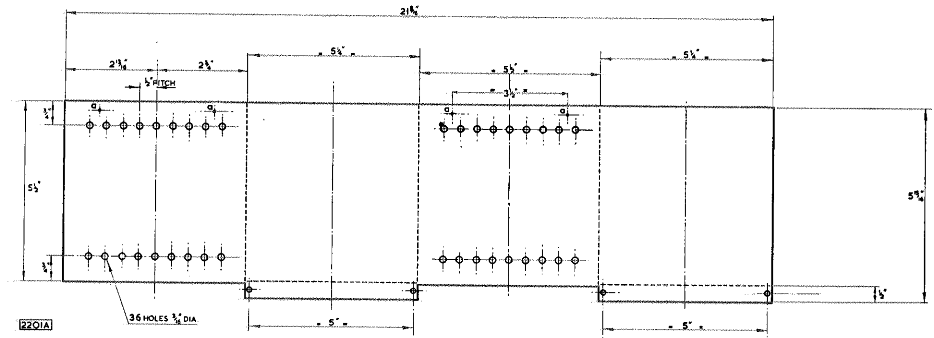
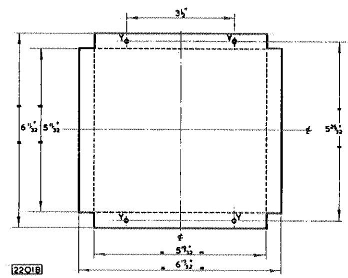


Fig. 3—Screening can for mains transformer
(a) (above) Can
(b) (near right) Lid
(c) (far right) Mounting plate



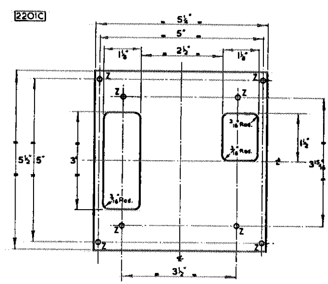
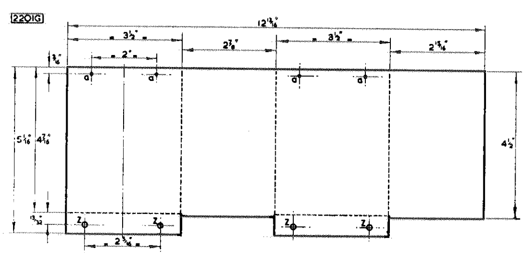
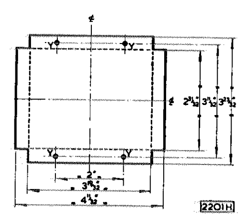
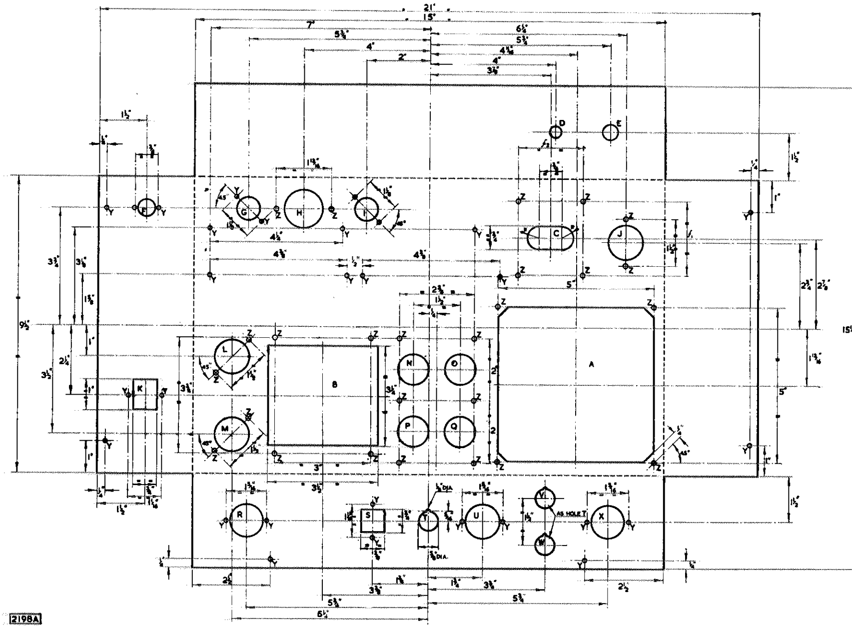


Fig. 4—Screening can for smoothing choke
(a) (near right) Can
(b) (far right) Lid






A
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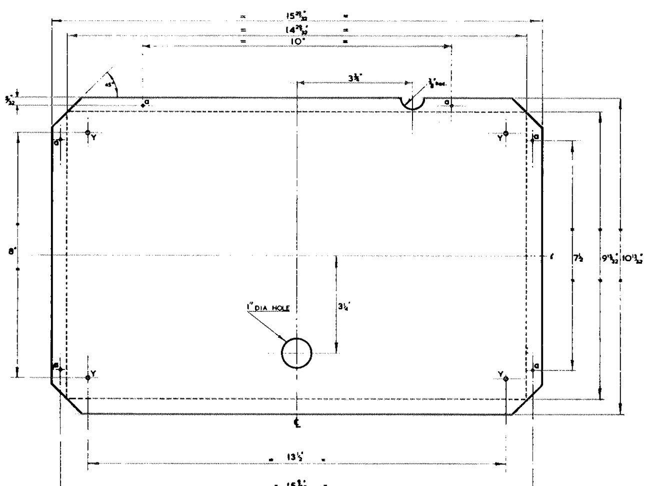
AS HOLE T
21"
15"
7"
4"
2"

2198A


1" DIA HOLE
10"
8"
$13\frac{1}{2}$"
$3\frac{1}{4}$"

2198B

CONSTRUCTION AND ASSEMBLY

The chassis and screening cans for the 20W amplifier are made from ten separate pieces of 16 s.w.g. aluminium sheet. The dimensions (in inches) of these pieces are:

(*a*) Main chassis	$21 \times 15\frac{1}{2}$
(*b*) Base	$15\frac{29}{32} \times 10\frac{13}{32}$
(*c*) Screening can (mains transformer)	$21\frac{9}{16} \times 5\frac{15}{16}$
(*d*) Can lid (mains transformer)	$6\frac{19}{32} \times 6\frac{11}{32}$
(*e*) Mounting plate (mains transformer)	$5\frac{1}{4} \times 5\frac{1}{2}$
(*f*) Screening can (output transformer)	$15\frac{13}{16} \times 5\frac{3}{16}$
(*g*) Can lid (output transformer)	$5\frac{3}{32} \times 4\frac{15}{32}$
(*h*) Mounting plate (output transformer)	$3\frac{5}{8} \times 4\frac{1}{4}$
(*i*) Screening can (smoothing choke)	$12\frac{13}{16} \times 5\frac{1}{16}$
(*j*) Can lid (smoothing choke)	$4\frac{11}{32} \times 3\frac{23}{32}$

Each piece should be marked as shown in the drawings of Figs. 2 to 5, and the holes should be cut as indicated. Where bending is required, it is important for the bends to be made accurately at the lines for the pieces to fit together properly on assembly.

Most of the resistors and small capacitors are mounted on two ten-way tagboards, and they should be connected as indicated in Figs. 6 and 7. The larger components should be fitted to the chassis in the positions indicated in the layout diagram of Fig. 8: this arrangement of the components will ensure good stability.

The wiring between the components is also indicated in Fig. 8. A busbar earth return is indicated, with only a single chassis connection at the input socket. Of the valveholders fitted to the chassis, only the holder for the EF86 needs to be skirted. This holder should also be nylon-loaded.

Fig. 5 (left)—Chassis details (the sections should be bent up at 90° at all dotted lines)

(a) (top) Main chassis. (The dimensions f1 and f2 will depend on the position of the fixing screws on the smoothing choke)

(b) (bottom) Base

KEY TO HOLES IN CHASSIS

Hole	Dimensions	Use	Type No.
A	—	Mains transformer	—
B	—	Output transformer	—
C	—	Smoothing choke	—
D	$\frac{3}{8}$ in. dia.	Pilot lamp. Bulgin	D180/Red
E	$\frac{1}{2}$ in. dia.	Mains switch. Bulgin	S300
F	$\frac{9}{16}$ in. dia.	Input socket, coaxial. Belling Lee	L.734/S
G	$\frac{3}{4}$ in. dia.	B9A nylon-loaded valveholder with screening skirt. McMurdo	XM9/AU, Skirt 95
H	$1\frac{1}{4}$ in. dia.	Electrolytic capacitors	—
I	$\frac{3}{4}$ in. dia.	B9A nylon-loaded valveholder, McMurdo	XM9/AU
J	$1\frac{1}{8}$ in. dia.	B8-O international octal valveholder McMurdo	B8/U
K	—	H.T. supply socket (for pre-amplifier) 6-way. Elcom	S.06
L	$1\frac{1}{8}$ in. dia.	B8-O international octal valveholder. McMurdo	B8/U
M	$1\frac{1}{8}$ in. dia.	B8-O international octal valveholder McMurdo	B8/U
N, O	1 in. dia.	Paper capacitor	—
P, Q	1 in. dia	Paper capacitor	—
R	$1\frac{1}{16}$ in. dia.	Output socket, 2-pin. Bulgin	P350
S	—	H.T. supply socket (for f.m. tuner) 4-way. Elcom	S.04
T	$\frac{5}{8}$ in. dia.	H.T. fuseholder. Belling Lee	L.356
U	$1\frac{1}{8}$ in dia.	Mains selector. Clix	CTSP/2
V	$\frac{5}{8}$ in. dia.	Mains fuseholder. Belling Lee	L.356
W	$\frac{5}{8}$ in. dia.	Mains fuseholder. Belling Lee	L.356
X	$1\frac{1}{16}$ in. dia.	Mains input socket, 3-pin. Bulgin	P340
Y	Drill No. 34	6B.A. clearance hole	—
Z	Drill No. 27	4B.A. clearance hole	—
a	Drill No. 49		

D.C. CONDITIONS

The d.c. voltages at points in the equipment should be tested with reference to Table 1. The results shown in this table were obtained with an Avometer No. 8.

PERFORMANCE

Distortion

The total harmonic distortion of the prototype amplifier at 400c/s, measured without feedback and with a resistive load, is shown in Fig. 9. The distortion

TABLE 1
D.C. Conditions

Point of Measurement		Voltages (V)	D.C. Range of Avometer* (V)
	C15	465	1000
	C12	440	1000
	C5	410	1000
	C4	160	1000
V3, V4 EL34	Anode	433	1000
	Screen grid	433	1000
	Cathode	32	1000
V2 ECC83	1st and 2nd Anode	325	1000
	1st and 2nd Grid	82·5	1000
	1st and 2nd Cathode	85	1000
V1 EF86	Anode	82·5	1000
	Screen grid	153·5	1000
	Cathode	2·2	25

*Resistance of Avometer:
1000V-range, resistance = 20MΩ
25V-range, resistance = 500kΩ

curve towards the overload point is also shown in Fig. 9 when feedback is applied.

At the full rated output, the distortion without feedback is well below 1% and with feedback is below 0·05%. The distortion rises to 0·1% for an output power of 27W. The loop-gain characteristic is such that a level of at least 20dB of feedback is maintained from 15c/s to 25kc/s, and of at least 26dB down to 30c/s.

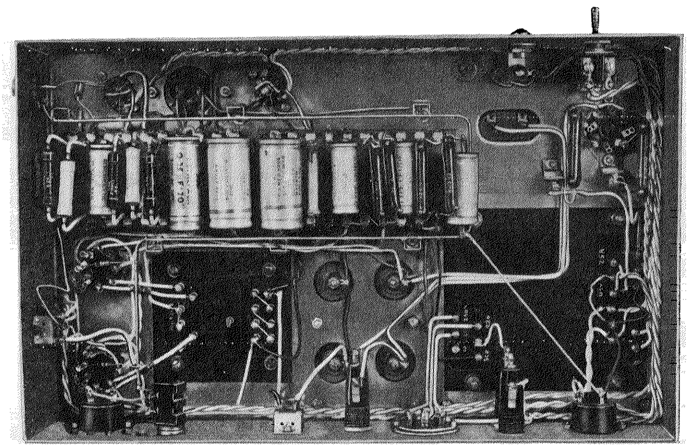
Measurements of intermodulation products were made in the prototype amplifier using a carrier frequency of 10kc/s and a modulating frequency of 40c/s. The ratio of modulating amplitude to carrier amplitude was 4 : 1. With the combined peak amplitudes of the mixed output at a level equivalent to the peak sine-wave amplitude at an r.m.s. power of 20W, the intermodulation products, expressed in r.m.s. terms, totalled 0·7% of the carrier amplitude. At an equivalent power of 27W, the products totalled 1% of the carrier amplitude. The beat-note distortion between equal-amplitude signals at frequencies of 14 and 15kc/s is 0·25 and 0·3% at equivalent powers of 20 and 27W respectively, and between frequencies of 9 and 10kc/s it is 0·2 and 0·25% at the same equivalent powers. The variations of intermodulation and beat-note distortion with equivalent power are plotted in Fig. 10.

The output/input characteristics of the prototype amplifier are shown in Fig. 9. Excellent linearity is indicated up to output voltages, measured across a 15Ω load, of 20V, which corresponds to an output power of 27W.

Frequency Response

The frequency- and power-response characteristics—that is, the curves for output powers of 1 and 20W respectively—are shown in Fig. 11. From this figure it will be seen that, at an output of 1W, the characteristic is flat (±1dB) compared with the level at 1kc/s from 2c/s to 100kc/s and the power response characteristic is flat (±0·5dB) from 30c/s to 20kc/s.

It is important that adequate power-handling capacity is available at the low-frequency end of the audible range and this is determined chiefly by the characteristics of the output transformer. The prototype amplifier is capable of handling powers of at least 20W at frequencies as low as 30c/s without excessive distortion, but for very low frequencies it is desirable that the signal should be attentuated in the associated preamplifier.



Underside View of Prototype Amplifier

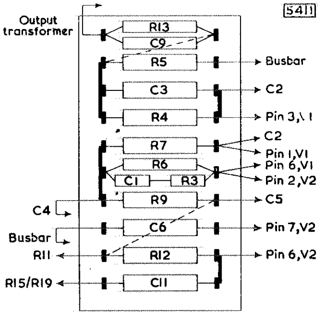


Fig. 6—Tagboard No. 1

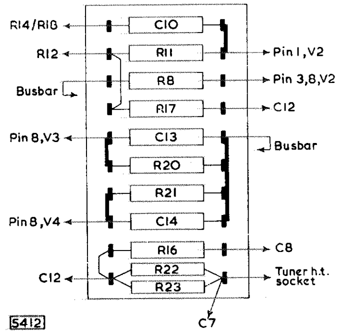


Fig. 7—Tagboard No. 2

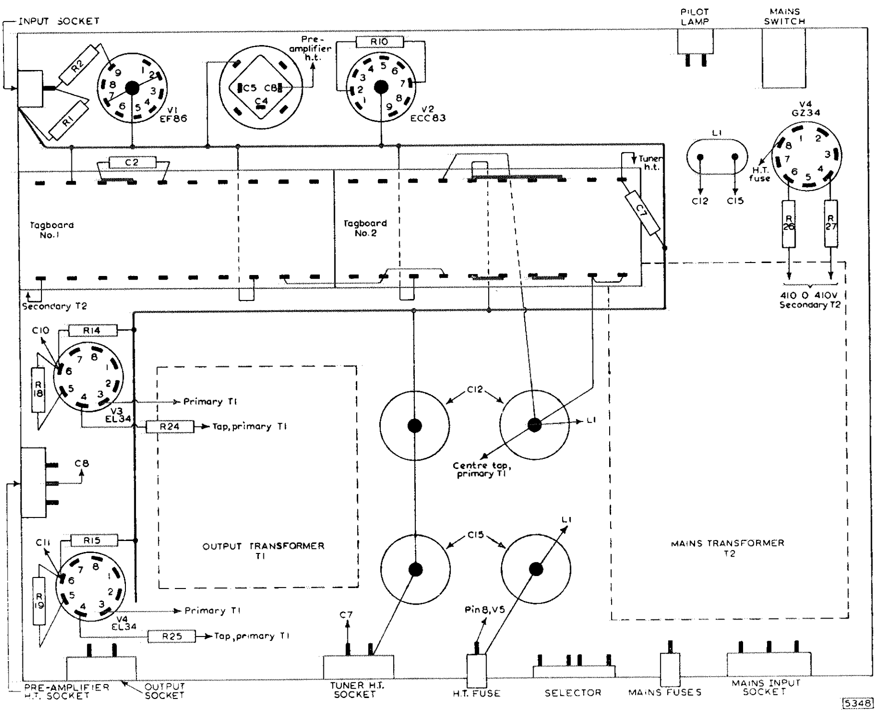


Fig. 8—Suggested component layout

Sensitivity

The sensitivity of the amplifier measured at 1kc/s is 6·5mV for an output of 20W when no feedback is applied, and approximately 220mV with feedback, the loop gain being 30dB. The loop gain characteristic of the complete amplifier for the full frequency range is shown in Fig. 11. The sensitivity, with feedback, at the overload point (27W) is approximately 300mV.

The level of background noise and hum in the prototype equipment is 89dB below 20W, measured with a source resistance of 10kΩ. This is equivalent to a signal of about 5·5μV at the input terminals. It is possible to increase the overall sensitivity of the amplifier by 6dB while still maintaining a low background level, a high loop gain and a good margin of stability, but various design requirements of associated pre-amplifier circuits (the need for a high signal-to-noise ratio, for example) render a higher sensitivity a doubtful advantage.

Phase Shift and Transient Response

Emphasis has been laid in the amplifier on a good margin of stability and, consequently, the phase shift is held to a comparatively low level. As shown in Fig. 11, the shift is only 20° at 20kc/s. Excellent response to transient signals is obtained, the rise time of the amplifier being of the order of 5μsec.

Output Impedance

The output stage has a low inherent output impedance, and this is further lowered by the use of negative feedback. It is approximately 0·3Ω with a 15Ω load for an output of 20W at frequencies of 40c/s, 1kc/s and 20kc/s. This gives a damping factor of about 50.

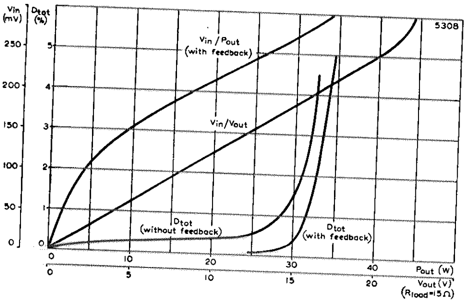


Fig. 9—Harmonic distortion and output/input characteristics

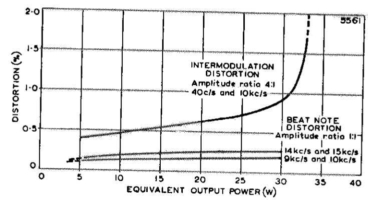


Fig. 10—Intermodulation and 'beat-note' distortion characteristics

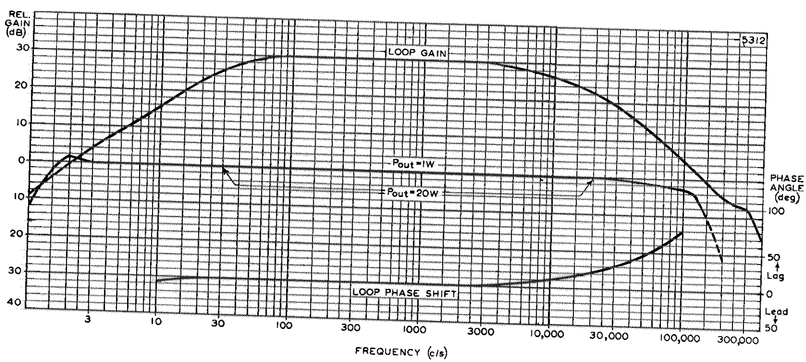


Fig. 11—Frequency-response, loop-gain and phase-shift characteristics