PHILIPS

CIRCUITS WITH THE ECL86 FOR MONO AND STEREO AMPLIFIERS

PHILIPS ELECTRON TUBE DIVISION

APPLICATIONS OF THE
A.F. TRIODE-POWER PENTODE ECL 86

INTRODUCTION

The range of tubes especially designed and produced for audio applications has been extended with a new type, viz. the ECL86. This type combines a high-mu triode with a high-slope power pentode in a noval envelope.

The combination of an amplifier triode and a power pentode in one envelope in itself is not new. (In the late thirties the VCL/ECL11 was a typical example; a more recent type is the ECL82.) New features are the very high gain, the high output power at low distortion and the high stability of the ECL86.

Fig. 1. Photograph of the ECL86 triode-power pentode.

For several years the tube range consisting of EF86, ECC83, EL84, EL86 and EL34 was considered adequate for almost all A.F. circuits, but when stereophony was introduced with its double-channel amplifiers, the tube complement would also have to be doubled and several amplifier designers took recourse to the ECL82 to limit the number of tubes. This tube was originally designed for use in TV receivers, primarily as a frame time base oscillator (triode section) and as a frame output tube (pentode section). Provision was made to render the tube also suitable for use as an AF amplifier and sound output tube; due to these properties the tube gained popularity in tape recorders up to the medium price class, and in electrophones.

However, in stereophony, where the input signals are lower than in monochannel operation, the gain of the ECL82 was considered slightly too low; although its characteristics allowed reproduction of good quality, this was difficult to realise. Therefore the demand arose for a new type with a higher gain and designed specially for AF applications. The answer to this demand is the ECL86, which contains in one envelope the active elements for a complete channel, when driven with a crystal or ceramic pick-up, and yet allowing a resonable amount of feedback.

DESIGN CONSIDERATIONS

In drafting the target specifications of the new tube, of course thoughts went in the direction of the power pentode EL84, unsurpassed in its class, although it was recognised that a power tube with an anode dissipation of 12 W cannot be combined with a triode in a noval envelope. However, a permissible anode dissipation of 9 W, was considered attainable. In fact, even a dissipation of 9 W posed a problem to the designers, the solution of which will be discussed later.

The gain of the new type should be such that an input voltage of 10 mV is sufficient to obtain a power output of 50 mW at a feedback factor of 2.5. This amounts to a sensitivity of 4 mV for 50 mV power output without feedback. The ECL82 requires 10 mV for 50 mW output.)

The screen grid current should be low. In class *AB* amplifiers it is usually the screen grid dissipation which sets a limit to the maximum attainable power output, and not the anode dissipation. For example: two ECL82 pentode sections could supply 17 W power output without the ratings for the anode dissipation being exceeded. The screen-grid dissipation, however, would then be far in excess of the ratings, so that the permissible output is only approximately 9 W.

Stability is another major problem in high-gain triode-pentodes. From the VCL/ECL11 it was known that stability could be obtained only by connecting a capacitor between the two anodes, which impairs the high-frequency response. For the ECL86 it was be investigated whether stability could be obtained without having recourse to external circuit elements.

It will be clear that possibility of introducing a double power pentode was also considered. However, the noval envelope allows of no higher anode dissipation than approx. 6 W per anode, so that both in single-ended and in push-pull stages the performance would be inadequate. In a two-channel single-ended stereo amplifier, for example, the output would be reduced by about 33% compared with the present standards. Likewise, in push-pull amplifiers an output power of 6 W is too low for Hi-Fi quality, a power of approx. 10 W being considered as a minimum. Moreover, the circuit lay-out with a phase splitter and push-pull output transformer is hardly justified considering that with a single-ended output stage equipped with one 12 W pentode the output power is only slightly less. Hence a double pentode in a noval envelope would result in a poorer performance whereas at present the general aim is to improve the quality of reproduction; therefore a combined high-gain triode and power pentode was considered the better proposition. The greater technological difficulties to be solved for manufacturing such a tube is more than outweighed by the superior performance that can be obtained.

SENSITIVITY AND STABILITY

The stability sets a limit to the gain of triode-power pentodes. Instability is caused by the feedback from the output to the input via the capacitance between the anode of the pentode and the grid of the triode. This feedback is positive, the output and input signals being in phase.

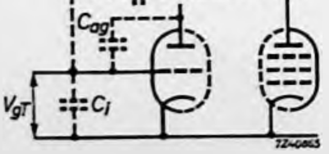


Fig.2. Simplified diagram of the ECL86 in an a.f. circuit. The parasitic capacitances, which give rise to feedback effects, are indicated by broken lines.

Fig.2 shows the interelectrode capacitances that influence the stability. The feedback voltage V_{gT} at the grid of the triode is:

$$V_{gT} = \frac{C_{aPgT}}{C_{aPgT} + C_i} V_a, \tag{1}$$

in which V_a denotes the output voltage, C_{aPgT} the anode pentode-to-grid triode capacitance and C_i the input capacitance (Miller capacitance).

Since $C_i >> C_{aPgT}$, eq.(1) reduces to:

$$V_{gT} = \frac{C_{aPgT}}{C_i} V_a = \frac{C_{aPgT}}{G_T \cdot C_{ag}} V_a \tag{2}$$

in which G_T is the gain of the triode and C_{ag} the anode-to-grid capacitance of the triode section.

Instability occurs when the product of the feedback via C_{aPgT} and the total gain of the amplifier exceeds unity. Therefore the stability condition is:

$$\frac{C_{aPgT}}{G_T \cdot C_{ag}} G_{tot} < 1 \tag{3}$$

in which G_{tot} denotes the total gain of the amplifier.

Denoting the gain of the pentode section, by G_p, gives:

$$G_{tot} = G_T \cdot G_P. \tag{4}$$

From eqs (4) in (3) it follows that the condition for stability is:

$$\frac{C_{aPgT}}{C_{ag}} \cdot G_P < 1 \tag{5}$$

Eq.(5) reveals that, in order to obtain a stable amplifier with a triode-pentode, the following requirements must be met:

(*a*) The ratio C_{aPgT}/C_{ag} should be as small as possible. However, for a good frequency response of the triode section C_{ag} should be small. Stability can therefore be ensured only by making C_{aPgT} extremely small.

(*b*) The gain of the triode section is irrelevant, that of the pentode, however, should be low.

CHARACTERISTICS OF THE TRIODE

The choice of the triode section was not difficult. A section of the ECC83 was taken as an example. It has a high gain and allows the design of an amplifier stage with a good response at the upper frequencies.

CHARACTERISTICS OF THE PENTODE

As stated above, from the point of view of stability the gain of the pentode should be low. In general, the gain of a pentode is: $G_P = S_{dyn} \cdot R_a$, in which S_{dyn} denotes the dynamical slope and R_a the load resistance. Now $S_{dyn} = S \cdot R_i/(R_i + R_a)$, in which S is the statical slope under operating conditions and R_i the internal resistance. Since $R_i >> R_a$, $S_{dyn} \doteq S$.

Unfortunately the load of a power tube (the loudspeaker) has a low impedance and must be coupled to the anode by means of a matching transformer which is not ideal, so that the load is not resistive but complex. As a rule the stray inductance and the self-capacitance of a transformer of good quality are low. However, they form a parallel resonant circuit, so that the load impedance of the pentode and hence G_P become very high at the resonant frequency of the output transformer.

The requirement of stability imposes an optimum value to the slope of the pentode if the other characteristics are given. However, the slope should be sufficiently high to obtain the required sensitivity. The internal resistance of the pentode can now be calculated by putting the two requirements imposed on the slope equal, and entering the feedback factor.

Denoting the feedback factor C_{aPgT}/C_{ag} in eq.(5) by β, it may be written to a good approximation:

$$R_i \approx R_a \frac{G_P - 1/\beta}{1/x\beta - G_P} \tag{6}$$

and

$$S = \frac{1}{R_a} G_P \quad 1 + \frac{1/x\beta - G_P}{G_P - 1/\beta} \tag{7}$$

in which x is the multiplication factor for the load resistance R_a caused by the reactance of the transformer at its resonant frequency, whilst G_P is the gain of the pentode at $x = 1$.

With $R_a = 7$ kΩ and the gain of one section of an ECC83 being known, the gain of the pentode can be calculated to be 62. For $W_o = 50$ mW the required input signal at the grid of the pentode will then be 0.3 V_{rms}. With these data and eqs (6) and (7), the internal resistance of the pentode and its slope were calculated as functions of $1/\beta$ with x as parameter. The results are plotted in Fig.3.

Test samples of the tube revealed that C_{aPgT} could be kept below 2 pF, whilst the C_{ag} was of the order of 1.4 pF. In a practical circuit with wiring and the tube holder capacitances included a value of 225 for $1/\beta$ could be realised. If under these conditions stability is required at $x = \infty$, the slope should be 12.5 mA/V and the internal resistance 16 kΩ, which is objectionable.

The island effect at the cathode caused by the high slope would lead to a low efficiency; moreover, the screen-grid current at full load would become high due to the low internal resistance.

It was therefore investigated at what characteristics stability could be obtained in the practical case of $x = 5$, and with $x = \infty$ if a simple additional external screening is employed.

It proved that with a circular screen on the tube holder with a height of 15 mm and an inner diameter of 22 mm, $1/\beta$ could be raised to about 525, so that with $R_i = 52$ kΩ and $S \approx 10$ mA/V both requirements could be met. The values eventually chosen were $S = 10$ mA/V and $R_i = 48$ kΩ.

CONSTRUCTION

The construction of the tube system differs in some respects from the conventional. A triode section of a ECC83 is much smaller than a power pentode. Therefore a "balcony construction" was adopted, which has several advantages (Fig.4).

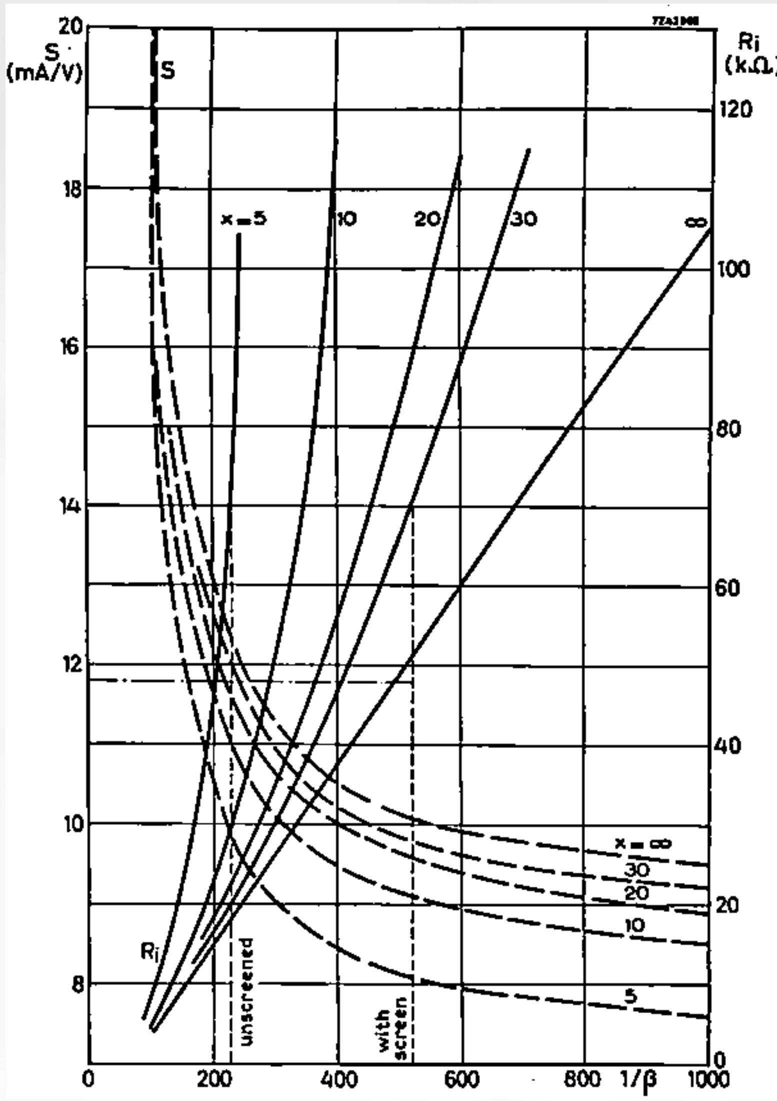


Fig.3. Relations between the characteristics of the pentode and the occurrence of instability. The slope and the internal resistance are plotted as functions of the feedback factor ($1/\beta$) with the reactance of the output transformer (x) as parameter. Instability occurs to the right of the broken lines if the input signal at the pentode is 0.3 V_{rms}, for 50 mW output and with an anode load resistance of 7 kΩ.

The anode of the pentode can now radiate heat over a much larger area than in the case of both systems being of equal height. Due to this measure the dissipation could be raised to 9 W.

A short triode system has the advantage that the electrodes are not easily set to vibration. The tendency to microphony, which is always present in high-gain tube systems, is further suppressed by resilient mounting of the triode system between the mica insulators.

The balcony construction also ensures low cross capacitances, yet additional measures have been taken to reduce C_{aPgT} and the capacitance between the grid and the heater of the triode.

A screening cap is placed on top of the triode system; moreover, the grid lead of the triode is almost completely surrounded by a box-shaped screen (see Fig.5). Both measures serve to reduce the C_{aPgT}. By these measures hum is also reduced because the C_{gTf} is low. Moreover, since the tube is designed for a.f. applications only, the most favourable pinning could be chosen. The grid connection of the triode and the anode connection of the pentode section are placed diametrically to ensure effective screening by the centre spigot of the tube holder. Hum is lowest when heater pin 4 is connected to earth.

In all tubes with a glass envelope some secondary emission from the inner side of the envelope will be experienced. The potential of the secondary emission surface approaches that of the electrode to which the secondary electrons flow, usually the anode. Now the anode potential consists of a d.c. component on which an a.c. component is superimposed. The secondary emission surface will

Fig. 4. The electrode system of the ECL86 triode-power pentode clearly showing the different lengths of the triode and the pentode sections. Note also the screening on the top of the triode section.

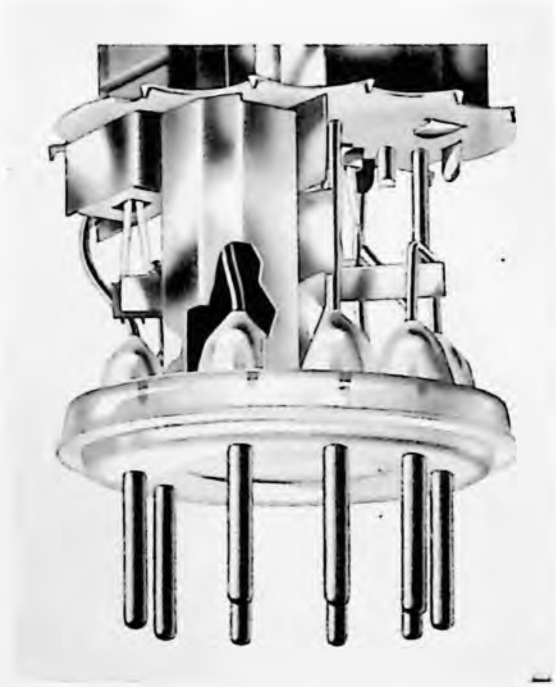


Fig. 5. Screening of the grid lead of the triode section.

therefore follow the a.c. potential, and this increases the feedback from the anode of the pentode to the grid of the triode, although its resistance is very high. In normal triode-pentodes the influence of this feedback is negligible, but at the gain of the ECL86 the influence might become noticeable at very low frequencies, especially in circuits with hum compensation via the output transformer. The envelope of the ECL86 is therefore made of lead glass instead of the lime glass that is usually employed.

Finally, precautions have been taken to ensure stable operation during life. The resistance of the leakage path between the electrodes causes another path for positive feedback. In a new tube this resistance is very high, but it decreases during life by deposits, mostly from cathode material, on the mica insulators and on the inner side of the tube base. In most types of tube this reduction in insulation is harmless, but in the ECL86 it might cause instability because a path for positive feedback is thus formed. Therefore a new type of cathode is used, which does not lead to difficulties even in the long run, whilst good emission is nevertheless ensured.

CONCLUSION

The ECL86 is an a.f. triode-power pentode having the following features:

- high gain,
- high stability,
- high efficiency,
- low microphony.

In a single amplifier without feedback the output is 4 W at 10% distortion, the required input voltage being only 46 mV_{rms}. In a push-pull class *AB* circuit without feedback, an output power of 14.3 W at 5% distortion is attainable at an input signal of 145 mV, the gain, of the phase-splitter being 60.

These figures show that the ECL86 can be universally employed in broadcast and TV receivers, in tape recorders, and in high-quality amplifiers, be it single-channel or sterophonic.

APPLICATIONS

Investigations carried out in our Application Laboratory resulted in the design of four experimental amplifiers. Two of these are single-tube amplifiers, with 3 W secondary output. The one amplifier is a mono-channel type and the other is an amplifier for stereo reproduction in which each channel is equipped with only one tube. Both constitute economic amplifier circuits which have a remarkable good quality of reproduction, considering the simple lay-out.

The other two amplifiers are of the Hi-Fi class with 9 W secondary output: a mono-channel amplifier and a stereophonic circuit. In these amplifiers the pentode sections of the ECL86's are connected in push-pull, the two triodes are used as a phase inverter and a pre-amplifier in a circuit with positive and negative feed-back. This circuit has a sensitivity of 0.5 V for full drive although 20 dB negative feedback is applied.

The photograph on this page shows the four amplifiers, those on the top row are the stereo types, those in front the mono-channel types. The two amplifiers on the right hand are the inexpensive types, those on the left hand the Hi-Fi types.

Economic A.F. amplifier with one ECL 86

The A.F. amplifier with one ECL86 is very simple but has nevertheless remarkably good features. The amplifier is suitable for use in electrophones, in the a.f. section of broadcast and T.V. receivers up to the medium price class, and for small radiograms. Full fledged tone control and provision for use with magneto-dynamic pick-up heads would be out of place in such a design. The amplifier may be driven either by ceramic or crystal pick-up heads, or by the detector section of a receiver. The tone controls comprise treble cut and bass boost. The latter may be omitted and replaced by a fixed resistor, the value of which is matched to the loudspeaker characteristics and the cabinet used.

SPECIFICATIONS

power output			3 W
sensitivity for full output			300 mV
harmonic distortion at 1000 c/s,	output 1 W		0.6 %
	output 2 W		0.9 %
	output 3 W		1.8 %
negative feedback			18 dB
frequency response, output 50 mW, -3 dB points below			10 c/s
			150 kc/s
power response, output 3 W, -3 dB points		at	60 c/s
			40 kc/s
tone control, bass boost at 75 c/s		max.	13 dB
treble cut at 10 kc/s		max.	16 dB
at 15 kc/s		max.	18 dB
hum and noise level with respect to full output			-70 dB

CIRCUIT DESCRIPTION

The typical features of this amplifier, its low distortion, its fine frequency response and its low hum and noise level, are atributable to the correct setting of the tube, the smoothing and decoupling and the output transformer.

Fig.6 shows the circuit diagram. The grid of the triode is connected to the volume control via potentiometer R_2, which forms the treble control with C_1. The triode section is set for maximum gain (about 70) at a supply voltage of 250 V and an anode load resistance of 220 kΩ. Under these conditions the total distortion is only 0.4 % at an output voltage of 3.2 V_{rms} which is, according to the tube data, the required input for the pentode section for maximum output (4 W at 10% distortion).

The pentode section is also operated with anode and screen-grid voltages of 250 V. The load resistance is 7 kΩ, the required cathode resistor is 170 Ω. Since the latter value is not available in the normal range of resistors, one resistor of 470 Ω and one of 270 Ω (0.5 W) are connected in parallel. These are the only resistors with a tolerance of ± 5%; all other resistors are of the ± 10 % tolerance range.

A negative feedback voltage is taken from the secondary of the output transformer via $C_6 R_9$ and $C_2 R_3$ and applied to the cathode of the triode section. For this purpose part of the cathode resistor is unbypassed. A negative feedback of 18 dB is thus obtained.

Bass boost is obtained by decreasing the feedback for the lower frequencies by means of C_6 and R_9. If R_9 increases the low frequency feedback decreases. Without feedback the input signal for 3 W output would be of the order of 26 mV. With feedback the sensitivity is reduced to 300 mV, which is adequate for use with either ceramic or crystal pick-up heads, or with a tuner. A higher sensitivity will make the amplifier to be overdriven easily when the volume control is set at maximum gain.

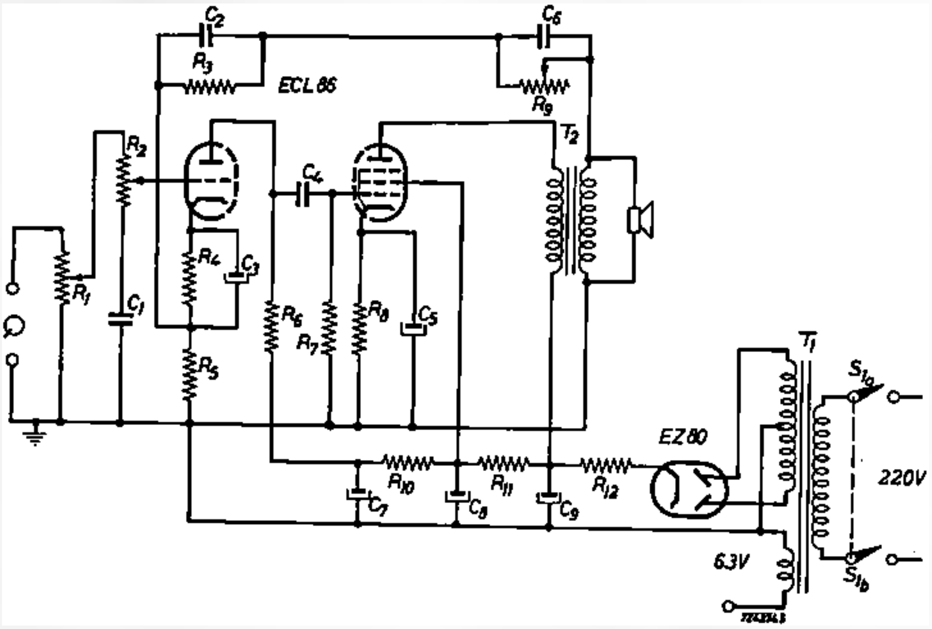


Fig.6. Circuit diagram of the inexpensive amplifier with one ECL86.

LIST OF PARTS

R_1 = 1 MΩ, log. carbon potentiometer
R_2 = 0.5 MΩ, log. carbon potentiometer
R_3 = 1.2 kΩ, ¼ W
R_4 = 1.8 kΩ, ¼ W
R_5 = 100 Ω, ¼ W
R_6 = 220 kΩ, ¼ W
R_7 = 470 kΩ, ¼ W
R_8 = 470 Ω ½ W } connected in parallel
270 Ω ½ W
R_9 = 10 kΩ, lin. carbon potentiometer
R_{10} = 10 kΩ, ¼ W
R_{11} = 2.7 kΩ, 5 W, wire wound
R_{12} = 390 Ω, 5 W, wire wound

C_1 = 150 pF, ceramic
C_2 = 820 pF, ceramic
C_3 = 100 µF, electrolytic, 4 V wkg.
C_4 = 0.1 µF, polyester, 400 V wkg.
C_5 = 100 µF, electrolytic, 16 V wkg.
C_6 = 0.22 µF, polyester, 125 V wkg.
C_7, C_8, C_9 = 3 × 50 µF, electrolytic, 350 V wkg.

T_1 = supply transformer AD9027
T_2 = output transformer AD9057

OUTPUT TRANSFORMER

The heavy negative feedback, which is essential for obtaining the required low distortion and the wide frequency range, imposes the condition that an output transformer of obtstanding quality is used. It must have low stray inductance and low winding capacitance, so that its resonant frequency is high, otherwise heavy feedback would lead to instability.

The transformer used has been specially developed for this amplifier; the type number is AD9057. It is a transformer with C-core of oriented laminated sheet. The primary winding is divided into two sections and the secondary is wound in between, so that the stray inductance is minimised. Moreover, the relatively high primary inductance of 10.5 H could be obtained with a low number of turns so that the capacitances are small. The resulting resonant frequency is thus raised to such a value that a feedback of 18 dB, which is very high for an amplifier of this type, can be applied without risk of instability.

SUPPLY

A standard type mains transformer type AD9027 is used in combination with a heater type rectifier EZ80. The transformer is over-dimensioned, the total current drain being only 42.5 mA at a voltage of 276 V across C_9. If the circuit is used in an electrophone, for example, semi-conductor rectifiers in a bridge circuit may be a more attractive solution for the H.T. supply. The transformer can then be wound for about 240 V, 50 mA, and a heater winding for 6.3 V, 0.7 A. The resistor R_{12} should be so dimensioned that the voltage across C_9 is 276 V.

A triple electrolytic capacitor of $3 \times 50\ \mu F$ is used for the smoothing, together with resistors R_{10} and R_{11}; the circuit is entirely conventional. The on-off switch can be combined with the volume control. This solution has been adopted in the circuit of Fig.7.

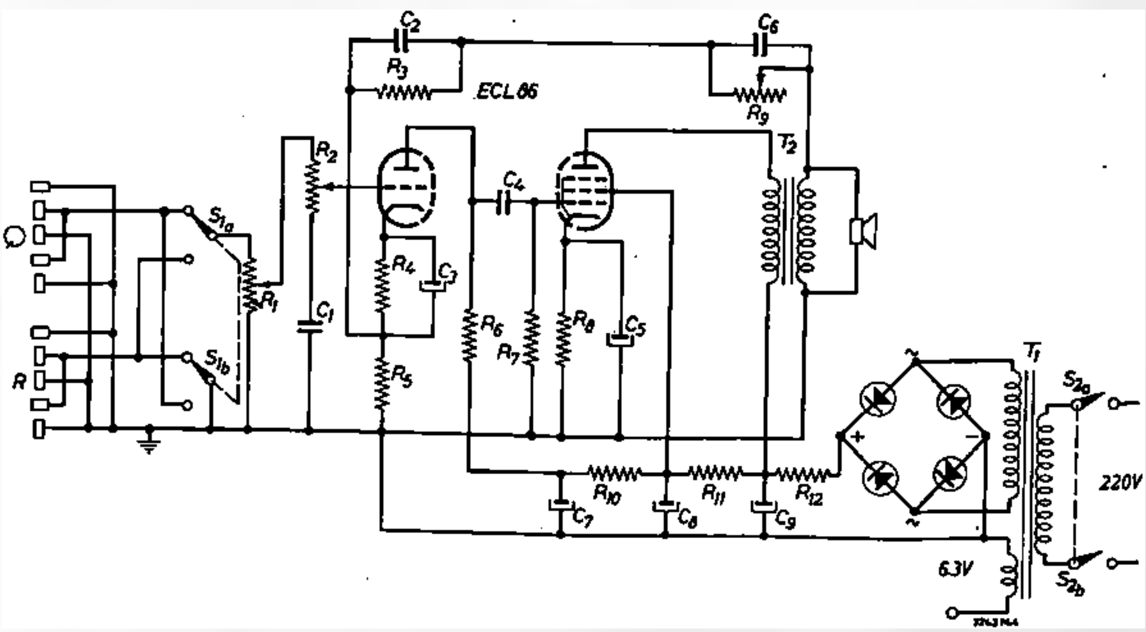


Fig. 7. Circuit diagram of the inexpensive amplifier with a selenium rectifier for the H.T. supply. The list of parts is identical to that for the amplifier of Fig.6, only the supply transformer is replaced by type 3W 602 88.1; the type number of the selenium rectifier is SR 250 B 75.

CONSTRUCTION

Fig.8 is a photograph of the test model, according to the circuit of Fig.7. It has been made as a separate unit, and input terminals for a pick-up and a tuner have been provided; the desired input can be selected by means of a switch on the front panel.

Selenium rectifiers are used for the H.T. supply. The economical circuit lay-out is also clearly demonstrated by this photograph.

MEASURED RESULTS

VOLTAGE AND CURRENTS

The following voltages and currents were measured in the experimental amplifier:

Supply				
EZ80	cathode-to-earth	292 V		
V_{C9}		276 V	total current drain	42.5 mA
V_{C8}		258 V		
V_{C7}		250 V		
ECL86				
pentode section				
	anode voltage	257 V	anode current	35.5 mA
	screen-grid voltage	258 V	screen-grid current	6.0 mA
	cathode voltage	7.4 V		
triode section				
	anode voltage	120 V	anode current	0.6 mA
	cathode voltage	1.1 V		

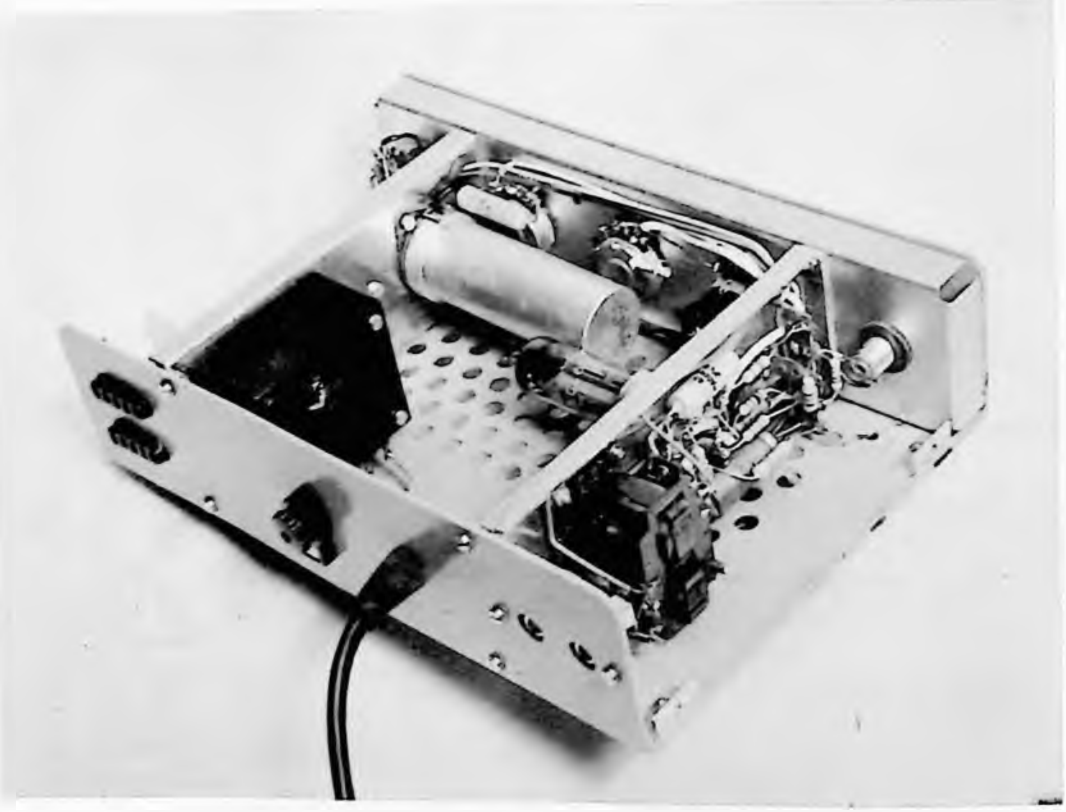


Fig.8. The interior of the experimental amplifier with one ECL86, according to the circuit of Fig.7. The modern construction of the "chassis" with horizontally mounted tube and electrolytic capacitor, ensures small dimensions and good ventilation.

FREQUENCY RESPONSE

The frequency response was measured at the secondary of the output transformer, (*a*) with the tone controls in the zero position, and (c and *d*) with these controls at maximum. The corresponding curves are shown in Fig.9.

POWER RESPONSE

The power response at 3 W output was measured at the secondary of the output transformer, the result is shown by curve (*b*) in Fig.9.

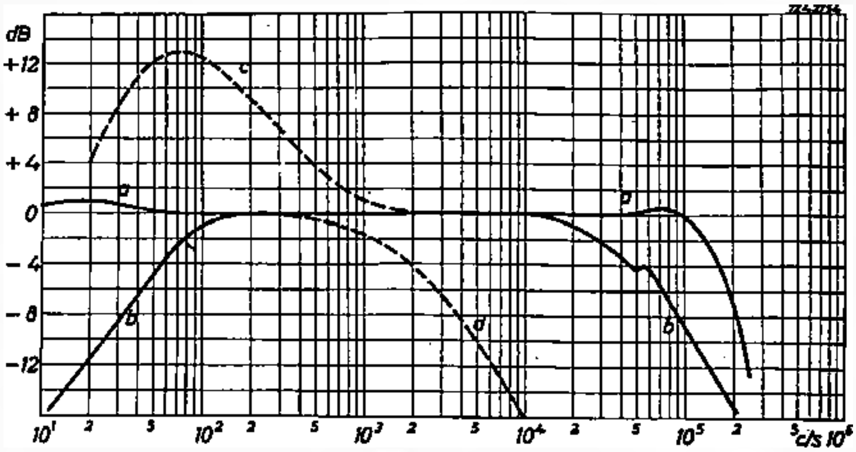


Fig.9. Frequency response (*a*) and power response (*b*) measured at 3 W power output. Curve (c) shows the maximum bass boost, and curve (*d*) the maximum treble cut of the amplifier with one ECL86.

HARMONIC DISTORTION

The harmonic distortion was measured at the secondary of the output transformer, at a frequency of 1 kc/s; the result is plotted in Fig.10. The curve is typical for an amplifier with heavy feedback and shows that the amplifier should not be driven beyond of 3.5 W output power.

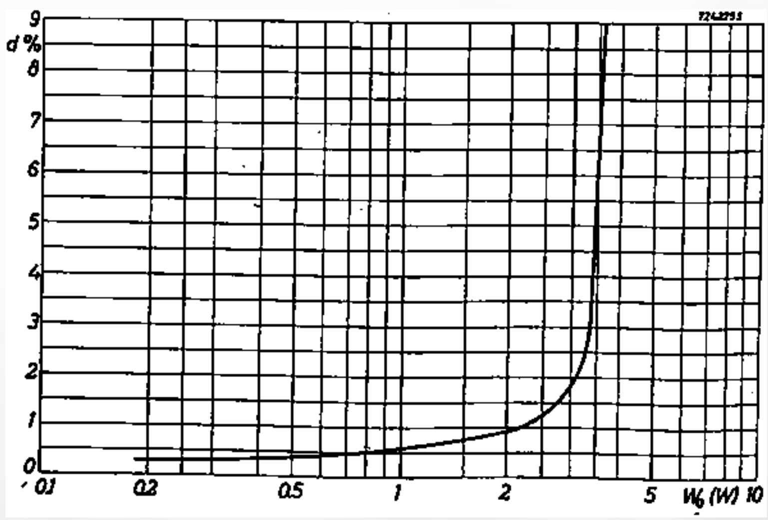


Fig.10. Harmonic distortion of the amplifier measured at a frequency of 1 kc/s.

STABILITY

The loop gain and loop phase characteristics plotted in Figs 11 and 12 respectively, show that the stability of the amplifier is adequate.

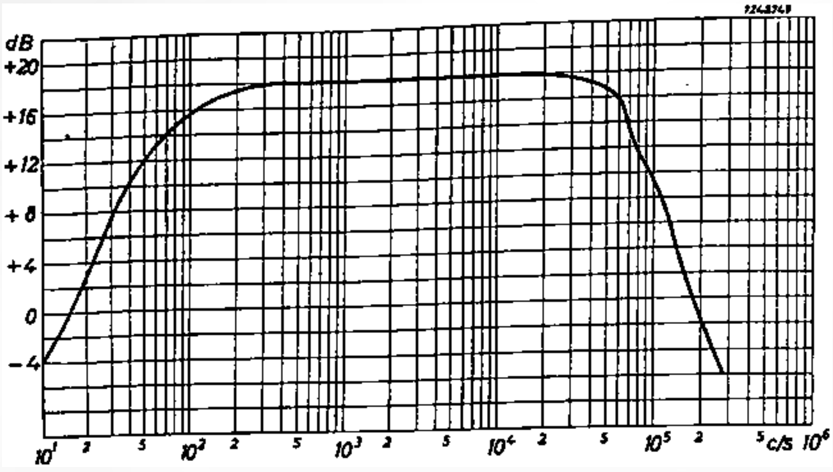


Fig. 11. Loop gain characteristic of the amplifier with one ECL86.

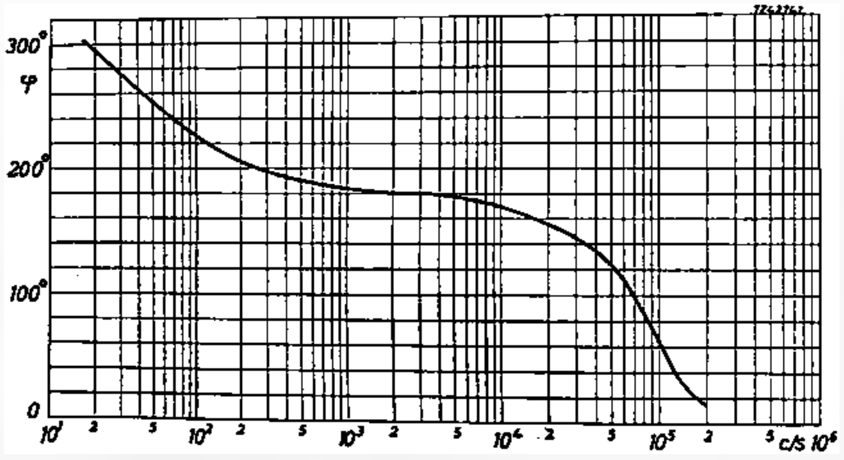


Fig. 12. Loop phase characteristic of the amplifier with one ECL86.

Stereophonic amplifier with one ECL 86 per channel

The stereophonic amplifier with one ECL86 per channel is essentially a doublet of the single-channel amplifier described in the preceding section. Apart from the fact that the potentiometers are ganged, a few components are added to obtain a real stereo circuit. These components are a balance control, a selector switch and a phase reverse switch.

SPECIFICATION

power output		2× 3 W
sensitivity for full output per channel		300 mV
harmonic distortion at 1000 c/s, output 1 W		0.6 %
output 2 W		0.9 %
output 3 W		1.8 %
negative feedback		18 dB
frequency response, output 50 mW, –3 dB points below		10 c/s
		150 kc/s
power response, output 3 W, –3 dB points		60 c/s
		40 kc/s
tone control, bass boost at 75 c/s	max.	13 dB
treble cut at 15 kc/s	max.	18 dB
hum and noise level with respect to full output		–70 dB
cross talk		–36 dB

CIRCUIT DESCRIPTION

Fig.13 shows the circuit diagram of the stereophonic amplifier with one ECL86 in each channel. Two inputs are provided, one for a monophonic tuner, the other for stereophonic pick-up heads. The four-position triple switch gives the following possibilities: (1) monophonic tuner, (2) stereo pick-up, (3) stereo reverse and (4) both pick-up input channels connected in parallel for monophonic reproduction. The positions 2, 3 and 4 are thus for record reproduction. In position 2, the left-hand pick-up leads are connected, via the left-hand amplifier channel, to the left-hand loudspeaker; similarly the right-hand pick-up leads are connected via the right-hand amplifier channel to the right-hand speaker.

In position 3 the pick-up leads are reversed; the left-hand leads are connected to the right-hand channel and speaker, and so forth.

The fourth position offers the possibility of reproducing monophonic records with a stereo or monophonic pick-up head.

The selector switch is followed by the balance control. It consists of ganged potentiometers type E 091 ZZ/01. In this type of potentiometer one half of each track is silver-coated so that in the centre position both runners are on the silver track. If the spindle is turned clockwise, the runner of the potentiometer in the left-hand channel passes onto the resistance track, whilst that of the potentiometer in the right-hand channel remains on the silver-coated track, and vice

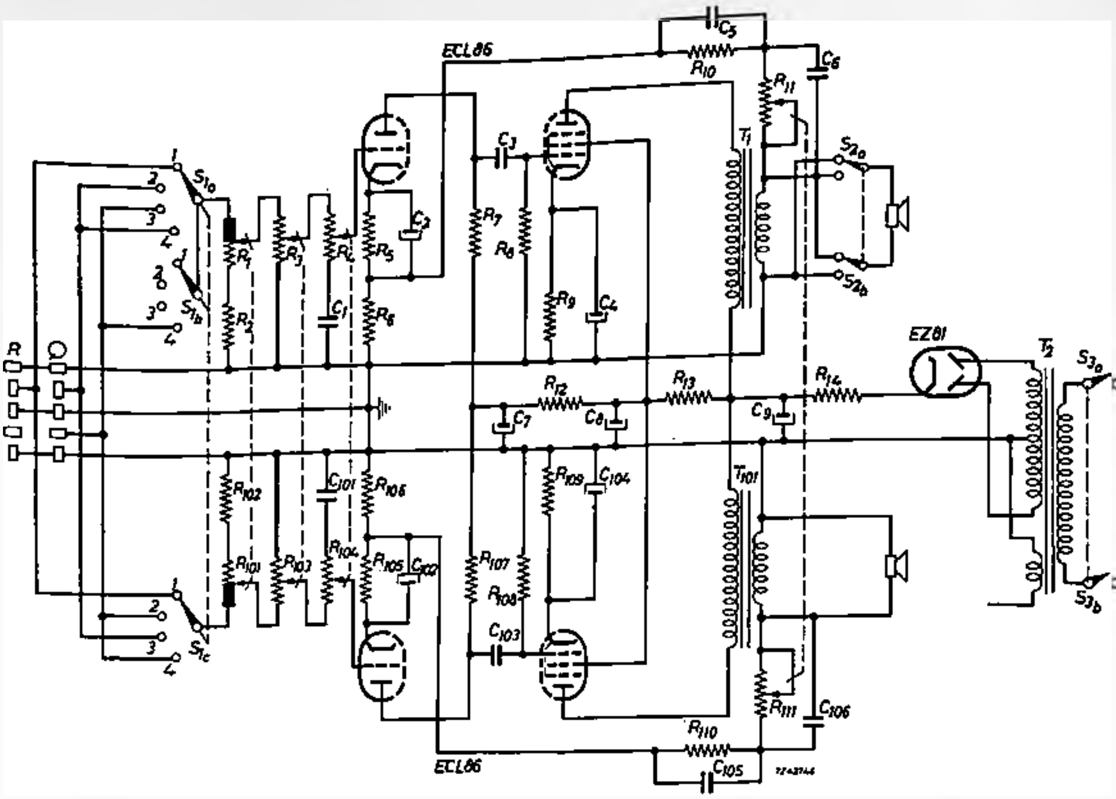


Fig. 13. Circuit diagram of the stereophonic amplifier with one ECL86 in each channel.

LIST OF PARTS

R_1, R_{101} = 1 MΩ, tandem balance control type E091ZZ/01
R_2, R_{102} = 470 kΩ, ¼ W
R_3, R_{103} = 1 MΩ, tandem carbon potentiometer log.
R_4, R_{104} = 0.5 MΩ, tandem carbon potentiometer log.
R_5, R_{105} = 1.8 kΩ, ¼ W
R_6, R_{106} = 100 Ω, ¼ W
R_7, R_{107} = 220 kΩ, ¼ W
R_8, R_{108} = 470 kΩ, ¼ W
R_9, R_{109} = 470 Ω ½ W, 270 Ω ½ W } connected in parallel
R_{10}, R_{110} = 1.2 kΩ, ¼ W
R_{11}, R_{111} = 10 kΩ, tandem carbon potentiometer lin.
R_{12} = 5.6 kΩ, ½ W
R_{13} = 1.5 kΩ, 5 W, wire wound
R_{14} = 270 Ω, 5 W, wire wound

C_1, C_{101} = 150 pF, ceramic
C_2, C_{102} = 100 μF, electrolytic, 4 V wkg.
C_3, C_{103} = 0.1 μF, polyester, 400 V wkg.
C_4, C_{104} = 100 μF, electrolytic, 16 V wkg.
C_5, C_{105} = 820 pF, ceramic
C_6, C_{106} = 0.22 μF, polyester, 125 V wkg.
C_7, C_8, C_9 } = 3 × 50 μF, electrolytic, 350 V wkg.

T_1, T_{101} = output transformers type AD9057
T_2 = power transformer type AD9026

versa. As a result, a clockwise rotation of the spindle attenuates the left-hand channel with respect to the right-hand channel, whilst anti-clockwise rotation attenuates the right-hand channel. In contrast to other systems with linear potentiometers, or with logarithmic plus anti-logarithmic potentiometers, only one channel is attenuated whilst the level of the other remains constant, so that the volume control need not be reset to prevent overload in one channel. An attenuation of 14 dB in one channel gives adequate balance control, therefore the variation per channel is limited to that value by means of resistors R_2 and R_{102}.

Similarly, the volume controls R_3 and R_{103} the treble controls R_4 and R_{104} and the bass boost controls R_{11} and R_{111} are ganged. For the rest the circuits of both channels are identical to that of the monochannel amplifier described previously.

MEASURED RESULTS

VOLTAGE AND CURRENTS

The following voltages and currents were measured in the experimental amplifier:

supply			
EZ81 cathode to earth	295 V		
$V\ C_9$	273 V	total current	80 mA
$V\ C_8$	255 V		
$V\ C_7$	248 V		

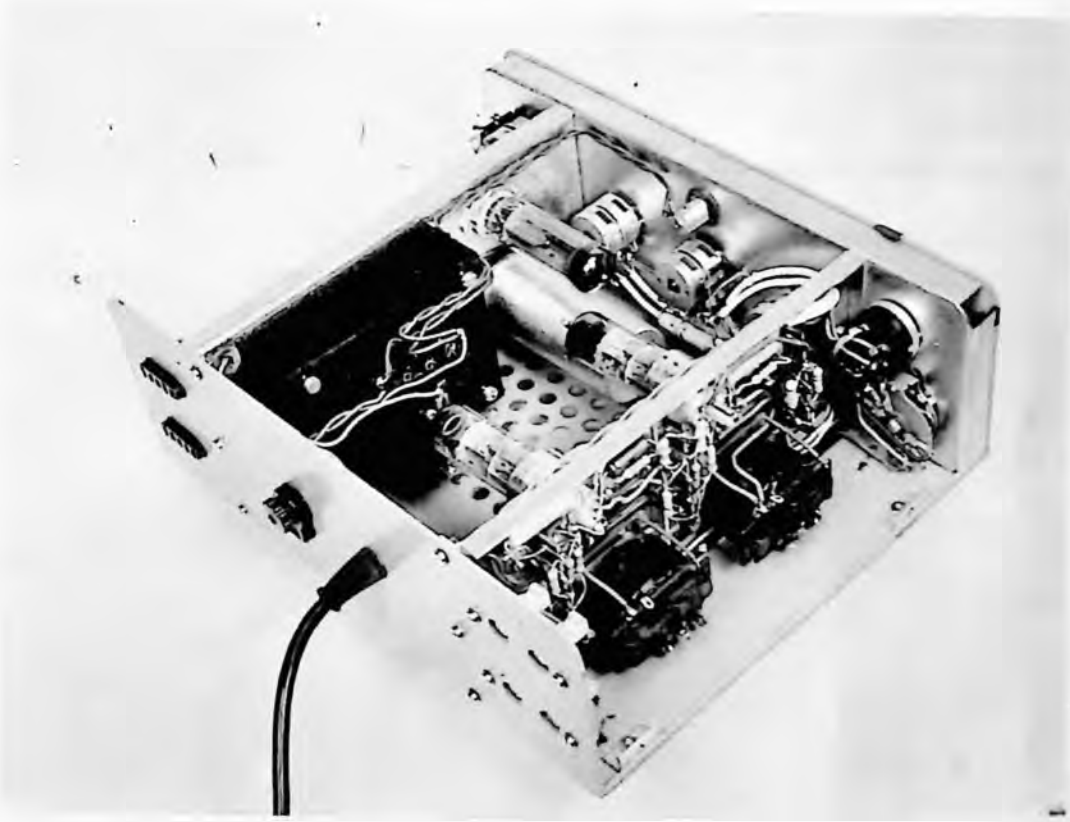


Fig. 14. Photograph of the interior of the experimental stereo amplifier with one ECL86 in each channel. The input is at the left, the selector switch and the balance control are mounted in the left-hand compartment, well screened from the other parts of the amplifier. The volume control and the tone controls are in the middle compartment. The right-hand compartment contains the main switch and the phase reverse switch and also the output terminals. The unconventional construction allows a good ventillation.

ECL86 (in each channel)

pentode section			
anode voltage	257 V	anode current	33.9 mA
screen-grid voltage	255 V	screen-grid current	5.5 mA
cathode voltage	6.7 V		
triode section			
anode voltage	120 V	anode current	0.6 mA
cathode voltage	1.1 V		

FREQUENCY RESPONSE

The frequency response was measured with the tone controls in the "flat" position and with maximum bass boost and maximum treble cut. The results were found to be identical to those of the mono-channel amplifier, the curves of which are shown in Fig.9.

POWER RESPONSE

The power response proved, to be identical to that of the mono-channel amplifier the curve of which is also shown in Fig.9.

HARMONIC DISTORTION

The harmonic distortion was identical to that of the mono-channel amplifier (see Fig.10).

LOOP GAIN AND LOOP PHASE CHARACTERISTICS

The loop gain and phase characteristics are identical to those of the mono-channel amplifier, the curves of which are given in Figs 11 and 12 respectively.

CROSS TALK

The cross talk between the channels measured at 1 kc/s proved to be −36 dB.

BALANCE CONTROL

The balance control was measured in each channel. The attenuation in the maximum positions of the ganged potentiometers was 14 dB in either channel.

Hi-Fi amplifier with two tubes ECL 86 in push-pull class AB

The best Hi-Fi amplifier designs are those in which the successive stages are well matched to each other so that no compromises or special measures are necessary to adapt the performance of one stage to that of following. Moreover, the number of tubes should be kept small, because every tube contributes to the distortion; therefore each tube should be adjusted for a high gain at low distortion.

The overall characteristics, such as power response and frequency response, should show a gradual roll-off at frequencies well beyond the audible range. The intermodulation distortion should be low.

Such a well-balanced design is described below. With only four tubes sensitivity is sufficient to operate the amplifier with magneto-dynamic pick-ups heads; R.I.A.A. frequency correction and a "Baxandall" tone control circuit have been incorporated.

SPECIFICATION

Tubes:	EF86	pre-amplifier		
	ECC82	second pre-amplifier and tone control		
	2 × ECL86	main amplifier		
	EZ81	full-wave rectifier		
Power output			max.	10 W
			nom.	9 W
Harmonic distortion at an output of:			10 W	9 W
and a frequency of:	60 c/s		0.75	0.3 %
	1 kc/s		0.4	0.2 %
	10 kc/s		0.75	0.4 %
Intermodulation distortion				
40 c/s and 10 kc/s ratio of amplitude 4 : 1			1.8	0.7 %
Sensitivity at 10 W output				
I. tuner				350 mV
II. tape recorder reproduction				1.5 V
recording				5 mV
III. crystal pick-up				45 mV
IV. magneto-dynamic pick-up				7 mV
Tone control: referred to 1 kc/s				
bass at 50 c/s		cut:		16 dB
		boost:		14 dB
treble at 10 kc/s		cut:		10 dB
		boost:		10 dB
Frequency response: within 1 dB from 20 c/s to 50 kc/s				
Power response: at 9 W flat from 44 c/s to 15 kc/s				
Negative feedback:				20 dB

Damping factor	14.5
Hum and noise, referred to 10 W power output	
input circuits I, II and III	−70 dB
input circuit IV	−55 dB
Stability:	
Capacitance across output terminals at which oscillations start, with	
a resistive load	56 nF
loudspeaker loading	12 nF

DESIGN CONSIDERATIONS

One of the problems in Hi-Fi amplifier design is a tone control circuit in which the "flat" frequency response can easily been set. In this respect the Baxandall circuit has many advantages: (1) bass and treble control is carried out with linear potentiometers, (2) the central point of those potentiometers is the "flat" position, (3) a control range, both for bass and treble controls, of +15 dB and −15 dB can easily been obtained, (4) in stereo amplifiers, where ganged potentiometers are used, superior ganging is obtained with linear potentiometers than with logarithmic types, (5) the distortion is low due to the high negative feedback.

All this seems ideal, but this circuit also has some disadvantages. The treble control should be equipped with a centre-tapped potentiometer, which is not commonly available. However, an artificial centre tapping, made with two identical resistors, shunted across a normal potentiometer, gives adequate results.

Moreover, the output impedance of the first tube should be low. A cathode follower could be ideal in this respect, but this would require an additional tube. A high-gain tube such as the ECC83, has an output impedance of about 62 kΩ, so that this type is not very attractive for this purpose, notwithstanding its high gain. Reference was therefore given to the ECC82, which has an output impedance of about 7 kΩ at a gain of 10 to 11.

According to the tube data, two pentode sections of the ECL86 operated at a supply voltage of 300 V, can deliver an output of 14.3 W to the primary of the output transformer at 5% distortion. Experiments with several circuits and output transformers revealed that in low-distortion feed-back amplifiers the maximum secondary output that could be obtained was of the order of 10 to 11 W. Under these conditions the input signal should be approximately 6.5 V_{rms}. Investigation of various phase splitter circuits with the triode sections and 20 dB overall feedback, revealed that an input signal of about 1.5 V is necessary for full drive. Such a sensitivity was considered too low, the aim being 0.5 V for full drive so that at input signals of 50 to 60 mV the main amplifier could be used with the tone control circuit described. This sensitivity is adequate for use with modern, high quality, ceramic and crystal pick-up heads.

The required sensitivity could be obtained by applying both positive and negative feedback in the main amplifier. Due to the positive feedback in the phase splitter, the gain could be increased to 175, without effects of instability and attention at the high frequencies. In this way the circuit was made suitable for use with various input sources (tape recorder, radio tuner, pick-up heads). However, the sensitivity is not yet adequate for use with magneto-dynamic pick-up heads and/or microphones.

To comply with the requirement to use such pick-up heads, a pre-stage with an EF86 is used in a frequency-dependent feedback circuit for R.I.A.A. correction.

It was considered inopportune to provide a microphone input. Microphones are usually employed with relatively long cables, so that it becomes general practice to incorporate a pre-amplifier in the stand. This makes an additional sensitive input channel in the amplifier superfluous, microphone amplifiers can be connected to one of the available inputs. This solution enables the use of a simple selector switch, which precedes the tone control stage.

CIRCUIT DESCRIPTION

The complete circuit diagram of the amplifier is shown in Fig.15. There are four input circuits, (*M*) for magneto-dynamic pick-up heads, (*C*) for ceramic and crystal pick-ups head, (*TR*) for tape recorder input and output, and (*R*) for a tuner. The inputs are selected by means of the four-position switch, which is provided with a short-circuiting section. In position 1, the grid of the EC(C)82 is connected to the anode of the EF86 via coupling capacitor C_5. The feedback network is also connected to this point. R_4 is the feedback resistor proper. Of the other elements, C_1 introduces an attenuation which increases with the frequency in excess of 1 kc/s. C_2 increases the gain for even lower frequencies. R_5 limits the gain at the lowest frequencies.

The feedback reduces the input impedance of the EF86 to about 4 kΩ. Therefore R_1 (68 kΩ) has been connected in series, so that the correct load resistance for the majority of magneto-dynamic pick-up heads is obtained. With the selector switch in position 2, the input channel for crystal pick-up heads is connected to the grid of the EC(C)82. The load resistance is then 1 MΩ. For both pick-up inputs female plugs according to the new I.E.C. standards were used. These are in such a way that either pick-up heads or mono-stereo pick-up heads can be connected to the same amplifier input.

Tape recorders are connected to the amplifier via a five-prong plug according to the DIN standard. Several modern tape recorders are provided with this type of plug and with the corresponding cable. The upper prong is the input, the lower one the output for recording. With the voltage divider $R_8 R_9$ the sensitivity is adjusted to 1.5 V, a value in accordance with several modern tape recorders, beyond the equaliser. Should the signal at the recorder output be lower, then the correct sensitivity can be obtained by changing the ratio of R_8 to R_9.

Finally, in the fourth position, a tuner can be connected to the input of the EC(C)82. R_{12} and R_{13} reduce the sensitivity to a value of 350 mV. C_{26} is shunted across R_{12} to compensate the attenuation at the high frequencies. The output signal of the EC(C)82 is fed to the tone-control network and to the recording terminal for the tape recorder via C_7, R_{10} and R_{11} reduce the output voltage to about 5 mV, which is sufficient for recording purposes.

The tone-control network is so dimensioned that the gain of the E(C)C82 is roughly unity. As in all sections of a pre-amplifier, the wiring of this stage of the circuit influences the performance. Long screened leads or screened leads with a high capacitance between core and screen should be avoided, especially to the grids of the E(C)C82 and to the volume control. The coupling capacitor C_{11} is connected to the junction of R_{20}, C_{12}, R_{22} and R_{23}. No direct voltage thus being across the capacitor, a type with a low working voltage and small dimensions can be used.

The volume control is at the input of the main amplifier. This has the advantage that the component which is the main cause of noise in amplifiers, is connected at a stage were the signal level is already fairly high, so that its influence on the signal-to-noise ratio is small.

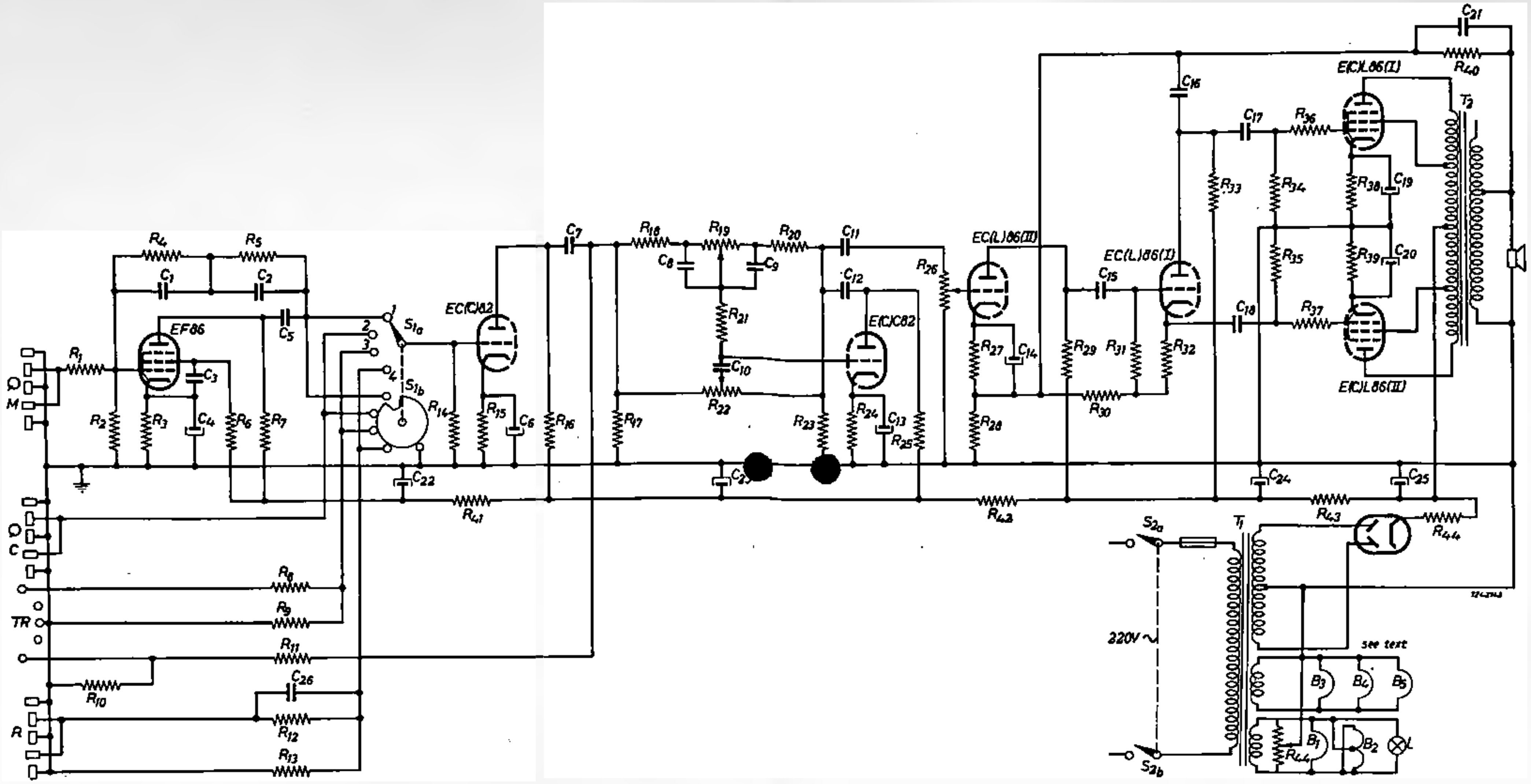


Fig. 15 -

LIST OF PARTS

R_1 = 68 kΩ, ¼ W
R_2 = 100 kΩ, ¼ W
R_3 = 2.2 kΩ, ¼ W
R_4 = 470 kΩ, ¼ W
R_5 = 10 MΩ, ¼ W
R_6 = 1.2 MΩ, ¼ W
R_7 = 220 kΩ, ¼ W
R_8 = 1 MΩ, ¼ W
R_9 = 47 kΩ, ¼ W
R_{10} = 10 kΩ, ¼ W
R_{11} = 1 MΩ, ¼ W
R_{12} = 820 kΩ, ¼ W
R_{13} = 150 kΩ, ¼ W
R_{14} = 1 MΩ, ¼ W
R_{15} = 1.2 kΩ, ¼ W
R_{16} = 47 kΩ, ½ W
R_{17} = 390 kΩ, ¼ W
R_{18} = 100 kΩ, ¼ W
R_{19} = 1 MΩ, carbon potentiometer lin.
R_{20} = 100 kΩ, ¼ W
R_{21} = 220 kΩ, ¼ W
R_{22} = 1 MΩ, carbon potentiometer lin.
R_{23} = 390 kΩ, ¼ W
R_{24} = 2.2 kΩ, ¼ W
R_{25} = 100 kΩ, ¼ W
R_{26} = 500 kΩ, carbon potentiometer log.
R_{27} = 1.5 kΩ, ¼ W
R_{28} = 120 Ω, ¼ W
R_{29} = 220 kΩ, ¼ W
R_{30} = 15 kΩ, ½ W
R_{31} = 1 MΩ, ¼ W
R_{32} = 1 kΩ, ¼ W
R_{33} = 15 kΩ, ½ W
R_{34} = 470 kΩ, ¼ W
R_{35} = 470 kΩ, ¼ W
R_{37} = 5.6 kΩ, ¼ W
R_{38} = 270 Ω, ½ W
R_{39} = 270 Ω, ½ W
R_{40} = 2.2 kΩ, ¼ W, 7 Ω matching
3.3 kΩ, ¼ W, 14 Ω matching
R_{41} = 5.6 kΩ, ½ W
R_{42} = 5.6 kΩ, ½ W
R_{43} = 1.2 kΩ, 5 W, wire wound
R_{44} = 39 Ω, 5 W, wire wound

C_1 = 200 pF, ceramic, 2 % tolerance
C_2 = 560 pF, ceramic, 2 % tolerance
C_3 = 0.1 μF, polyester, 400 V wkg.
C_4 = 100 μF, electrolytic, 4 V wkg.
C_5 = 22 nF, polyester, 400 V wkg.
C_6 = 100 μF, electrolytic, 4 wkg.
C_7 = 0.22 μF, polyester, 400 V wkg.
C_8 = 3.3 nF, ceramic, 10 % tolerance
C_9 = 3.3 nF, ceramic, 10 % tolerance
C_{10} = 100 pF, ceramic, 10 % tolerance
C_{11} = 0.1 μF, polyester, 125 V wkg.
C_{12} = 0.1 μF, polyester, 400 V wkg.
C_{13} = 100 μF, electrolytic, 4 V wkg.
C_{14} = 25 μF, electrolytic, 25 V wkg.
C_{15} = 0.1 μF, polyester, 400 V wkg.
C_{16} = 150 pF, ceramic, 10 % tolerance
C_{17} = 0.22 μF, polyester, 400 V wkg.
C_{18} = 0.22 μF, polyester, 125 V wkg.
C_{19} = 100 μF, electrolytic, 16 V wkg.
C_{20} = 100 μF, electrolytic, 16 V wkg.
C_{21} = 680 pF, 7 Ω matching
390 pF, 14 Ω matching
C_{22} = 16 μF, electrolytic, 350 V wkg.
C_{23}, C_{24}, C_{25} = 3 × 50 μF, electrolytic, 350 V wkg.
C_{26} = 10 pF, ceramic

Transformers

T_1 : AD9026
T_2 : AD9058

Input terminals

M, C, R : standard I.E.C. (five prong)
TR : standard DIN (five prong)

The triode sections of the two tubes ECL86 in the main amplifier are used as an amplifier and a phase splitter. Positive feedback is introduced by R_{28}, which is common to both triodes; as a result a signal with zero phase shift (360°) is fed to the grid circuit of the first triode. Which such a circuit a gain in excess of 700 can be obtained, albeit over a narrow frequency band, and with a tendency to instability. With the values of resistors selected, the gain is 175, the high-frequency response is still unaffected, and stability is ensured. The output impedances of the phase splitter are higher at the anode side than at the cathode side. This asymmetry might give rise to a considerably difference in frequency response of the two driver signals, this phenomena is avoided by using resistors of a low value for R_{30} and R_{33} (15 kΩ). For identical amplitudes of the driver signals, the sum of the values of resistors R_{28}, R_{30} and R_{32} should be equal to that of R_{33}. Because R_{28} and R_{32} have low values compared with R_{30}, the latter resistor could be kept equal to R_{33} without the balance of the signal being upset.

The pentode sections of the triode-pentodes ECL86 are used in a distributed load circuit (also called ultra-linear circuit, or screen-grid feedback circuit). The advantages of this circuit are generally known, so that there is no need to enlarge upon the subject here. Especially in this amplifier, in which positive and negative feedback are used, the requirements set to the output transformer are high. The necessary stability and frequency response could not be obtained with the currently available types. Therefore a new transformer, with C core, was designed. The type number of this transformer is AD9058. If a random transformer is used, it is not immaterial which of the triodes is used as the phase splitter and which as the amplifier. The signal at the anode of the pentode should be in phase with the input signal of the same tube. Hence, the phase splitter is combined with the upper pentode in the circuit diagram and the amplifier triode with the lower pentode. If the triodes are connected the other way round and a random transformer is used, considerable attenuation at the upper end of the response curve might occur. With transformer AD9058 this attenuation is negligible (–1.5 dB at 250 kc/s).

The negative feedback voltage is taken from the secondary of the output transformer, via R_{40}, R_{28}; 20 dB feedback is applied. C_{21} is shunted across R_{40} for phase correction at high frequencies, stability thus being improved. The quoted values of R_{40} and C_{21} apply to the 7 Ω loudspeaker tapping. With a 14 Ω loudspeaker combination, the complete secondary should be used, and the feedback voltage should be taken from the loudspeaker connections. In that case R_{40} should be increased from 2.2 kΩ to 3.3 kΩ, and C_{21} decreased from 680 pF to 390 pF.

The frequency response of this circuit proved to be very good. Without C_{16}, the attenuation at 250 kc/s was only 5 dB. However, when the output stage was driven into the grid current region, oscillations occurred at a frequency of about 600 kc/s. This could be prevented by applying some negative feedback from the anode of the phase splitter to the cathode of the amplifier tube via C_{16}. This measure increases the attenuation at frequencies in excess of 100 kc/s.

The standard supply transformer type AD9026 is used. The total H.T. current drain of the amplifier is 79 mA, the heater current is 2.9 A, with the rectifier EZ81 included. The AD9026, however, can supply the following outputs 2× 280 V, 90 mA; 6.3 V, 3.5 A; 6.3 V, 1.1 mA and 5 V, 1.1 A. Therefore this transformer is slightly overrated.

The heaters of the ECL86 tubes and of the rectifier are connected to the 3.5 A winding, pin 4 of the heaters being connected to chassis. The pre-amplifier tubes EF86 and ECC82 are fed from the 1.1 A winding, which is connected to chassis via the runner of a potentiometer R_{44}, which offers the possibility of reducing the hum level to a minimum.

There is no objection to ganging the mains switch with the volume control; the signal level at the latter is sufficiently high so that no noticeable hum is introduced.

The amplifier is mounted on an unconventional chassis to allow the use of short and low-capacitance grid connections, a logical sequence of the control elements, and, last but not least, a well ventilated and yet small cabinet. Figs 16 and 17 show the interior and the mounting of the amplifier.

MEASURED RESULTS

VOLTAGES AND CURRENTS

Voltage at C_{25}	317 V	
C_{24}	307 V	Total current drain 79 mA
C_{23}	275 V	
C_{22}	270 V	

	ECL86 (I)		*ECL86 (II)*	
Pentode section				
Anode	310 V	30 mA	310 V	30 mA
Screen grid	314 V	4.9 mA	314 V	4.9 mA
Cathode	9.5 V		9.5 V	
Triode section				
Anode	280 V	1.8 mA	150 V	0.71 mA
Cathode	30 V		1.4 V	

ECC82		
Second section		
Anode	95 V	1.8 mA
Cathode	4 V	
First section		
Anode	121 V	3.3 mA
Cathode	4 V	
EF86		
Anode	107 V	0.74 mA
Screen grid	93 V	0.15 mA
Cathode	2 V	

FREQUENCY RESPONSE

The frequency response was measured at the secondary of the output transformer, (*a*) with the tone controls in the centre position; (*b*) with the bass control at maximum and the treble control at minimum; (*c*) with the bass control at minimum and the treble control at maximum (see Fig.18). These curves were measured with the volume control in the maximum position.

The slight deviation of curve (*a*) at about 200 c/s remains within one dB. It can be remedied by decreasing the value of the bypass capacitor of R_{24}; however, this will also decrease the maximum bass boost by a few decibells. When C_{13} is

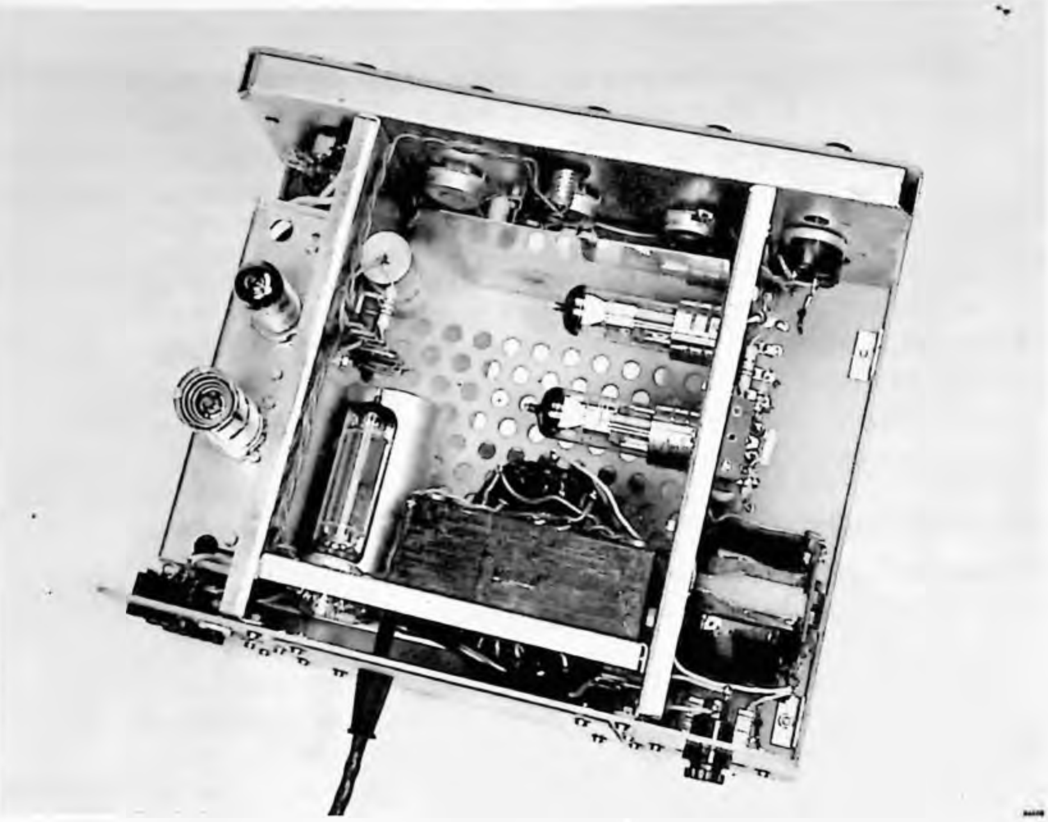


Fig.16. Photograph showing the interior of the experimental Hi-Fi amplifier with 2 × ECL86 in class *AB* push-pull. The pre-amplifier tube for magneto-dynamic pick-up driving is mounted in a screening can on the same-sub-chassis on which the ECC82 for the tone control circuit is mounted. The selector switch is mounted in the same compartment. The control potentiometers in the middle compartment form the connection with the main amplifier in the right-hand compartment. The supply section is mounted close to the back pannel in the middle compartment, but the mains switch is at the extreme right. To reduce hum, a screen is placed behind the control potentiometers.

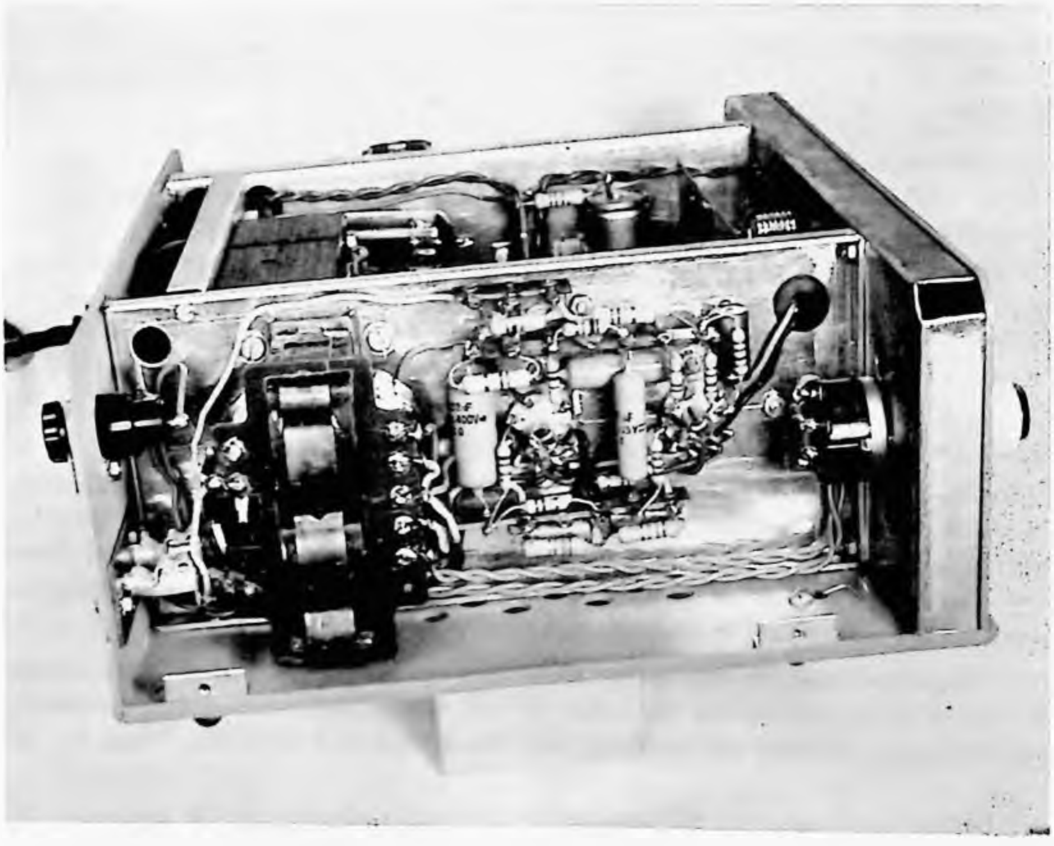


Fig. 17. This photograph clearly shows the compact mounting of the main amplifier. Note also the small dimensions of the output transformer with C core.

given a value of 0.1 μF, the response curve will remain flat between 50 and 1000 c/s.

POWER RESPONSE

The power response at 1 % distortion is plotted in Fig.19. It is seen that an output of 10 W is obtained between 60 c/s and 10 kc/s. At an output power of 5 W the range from 45 c/s to 15 kc/s is covered.

HARMONIC DISTORTION AND INTERMODULATION DISTORTION

The harmonic distortion was measured at frequencies of 1 kc/s, 60 c/s and 10 kc/s. The curves thus obtained are shown in Fig.20. It is seen that at 10 W output power the distortion remains below 0.75 %, but this point is very close to the sudden increase in distortion which is characteristic to all heavily feedback amplifiers. An output power of 9 W is a safe value.

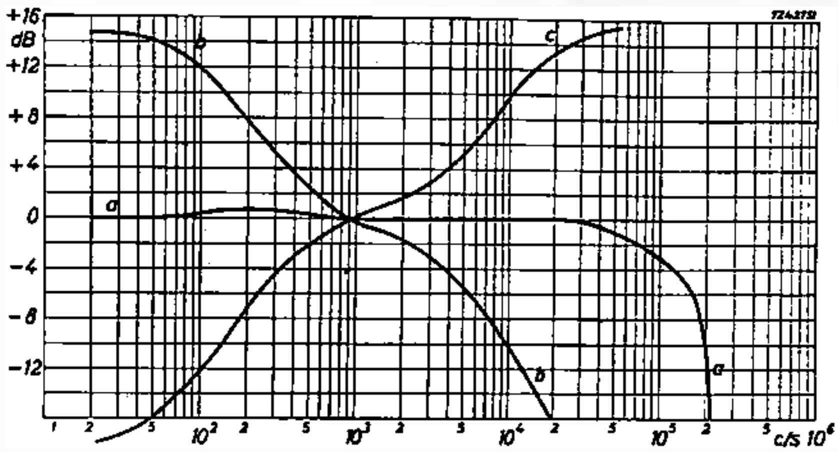


Fig. 18. Frequency response of the Hi-Fi amplifier with 2 × ECL86 in push-pull class *AB*; (*a*) with the tone controls in the "flat" position, (*b*) with maximum bass boost and maximum treble cut, (*c*) with maximum bass cut and maximum treble boost.

The curve of the intermodulation distortion is plotted in Fig.21. It is seen that at 9 W output power the I.M. distortion remains below 0.5 %, but at 10 W it increases to 2 %.

Since the power response, the harmonic distortion and the intermodulation distortion comply with stringent requirements at an output power of 9 W, it is on the safe side to call this amplifier a 9 W amplifier.

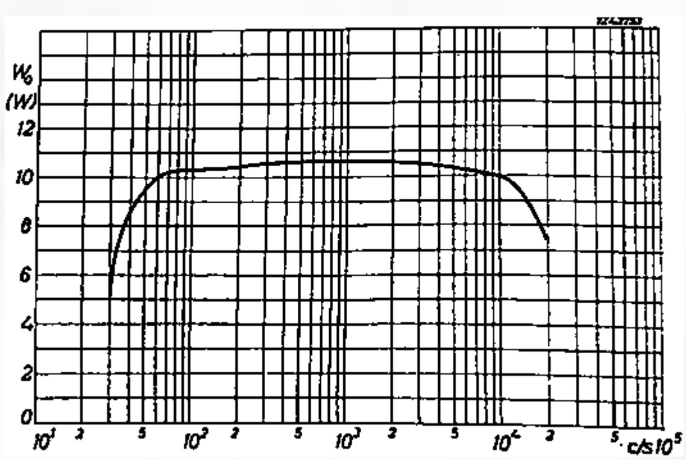


Fig. 19. Power response of the Hi-Fi amplifier with 2× ECL86, measured at 1% harmonic distortion.

PHASE SHIFT

Fig.22 shows the phase shift between the input and the output signal. It is seen that the phase shift remains below 25° between 25 c/s and 25 kc/s.

R.I.A.A. CORRECTION

The correction characteristic for magneto-dynamic pick-up heads, shown in Fig.23, reveals that the correction is practically according to R.I.A.A. standards.

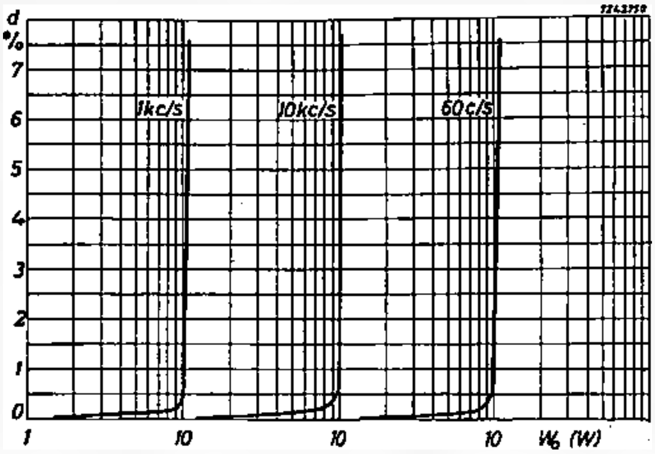


Fig.20. Harmonic distortion of the Hi-Fi amplifier measured at frequencies of 1 kc/s, 60 c/s and 10 kc/s.

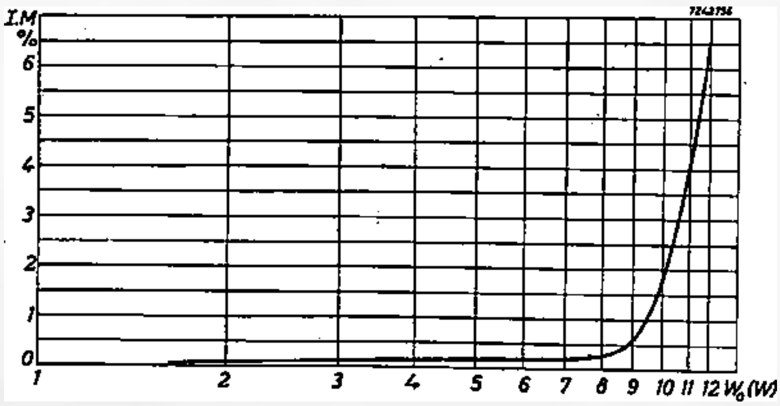


Fig.21. Intermodulation distortion measured at frequencies of 40 c/s and 10 kc/s with an amplitude ratio of 4 : 1. The equivalent output power is indicated.

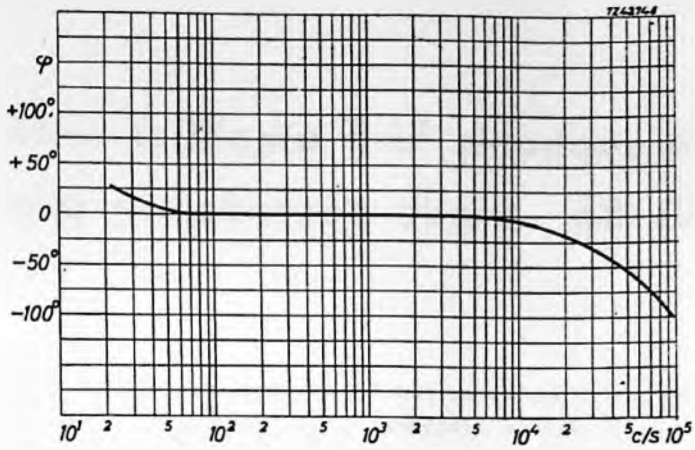


Fig. 22. Phase shift between the input and the output of the Hi-Fi amplifier as a function of the frequency.

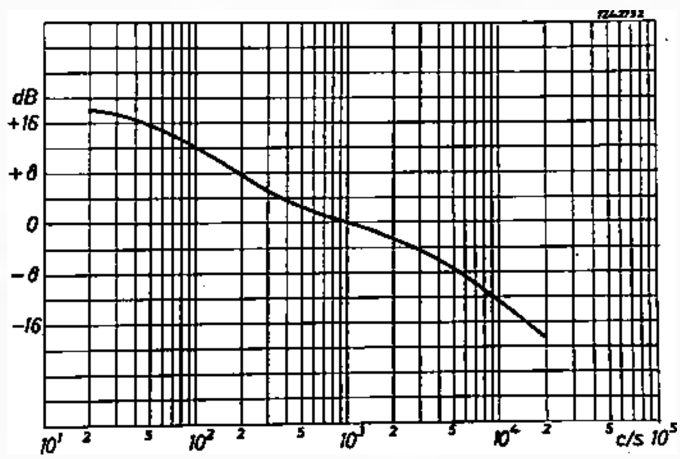


Fig. 23. Curve showing the correction characteristic of the pre-stage with an EF86, for use with magneto-dynamic pick-up heads.

Stereophonic hi-fi amplifier with
2x2 ECL 86 triode-pentodes in push-pull

The stereophonic amplifier described below consists essentially of two single-channel Hi-Fi amplifiers, as described in the preceding section. The selector switches and the potentiometers are ganged; a balance control, a function switch and a phase reverse switch are added. All input terminals are for stereophonic sources, also the tuner input. The function switch has the following positions (1) stereo, (2) stereo-reverse, (3) monochannel with both input circuits operating in parallel and (4) monochannel with input via the left-hand input channel and the main amplifiers operating in parallel.

SPECIFICATION

Tubes:	2 × EF86	pre-amplifier
	2 × ECC82	second pre-amplifier and tone control
	4 × ECL82	main amplifier
	2 × EZ81	full-wave rectifier

Power output, each channel			max.	10 W
			nom.	9 W
Harmonic distortion at an output of			10 W	9 W
	and a frequency of:	60 c/s	0.75	0.3 %
		1 kc/s	0.4	0.2 %
		10 kc/s	0.75	0.4 %
Intermodulation distortion				
40 c/s and 10 kc/s, ratio of amplitude 4 : 1			1.8	0.7 %
Sensitivity for 10 W output				
	I) tuner			350 mV
	II) tape recorder reproduction			1.5 V
	recording			5 mV
	III) crystal pick-up			45 mV
	IV) magneto-dynamic pick-up			7 mV
Frequency response: within 1 dB from 20 c/s to 50 kc/s				
Power response: 3 dB down at 35 c/s and 19 kc/s				
Balance control, one channel with respect to the other, attenuation			max.	12 dB
Tone control referred to 1 kc/s				
	bass at 50 c/s	cut:		16 dB
		boost:		14 dB
	treble at 10 kc/s	cut:		10 dB
		boost:		10 dB
Negative feedback:				20 dB
Damping factor:				14.5
Cross talk				−41 dB
Hum and noise, referred to 10 W power output per channel,				
	input circuits I, II and III			−70 dB
	input circuit IV			−55 dB

Stability:

Capacitance across output terminals at which oscillations start,

	resistive load	56 nF
	loudspeaker loading	12 nF

CIRCUIT DESCRIPTION

The circuit diagram is shown in Fig.24 both channels are essentially identical to the amplifier described in the preceding section. The selector switches and the potentiometers are ganged to facilitate the control; a balance control, a function switch and a phase reverse switch are incorporated to complete the circuit.

A central H.T. supply line is used for the two channels, so that corresponding anodes and screen grids are fed via common dropping resistors and decoupled by common capacitors. Two EZ81 double-anode rectifier tubes are used in the supply section. A single GZ34 may be used instead; however, in that case the heater should be fed from a 5 V winding on the supply transformer.

Balance control is achieved by means of a tandem potentiometer type E 091 ZZ/01, which gives no attenuation in the central position. If the potentiometers are turned clockwise only the left-hand channel is attenuated, when turned anti-clockwise the right-hand channel is attenuated, in both cases with reference to the condition in the central position.

The function switch S_2 is connected between the pre-amplifier and the main amplifier stages. The positions are: (1) stereo; (2) stereo reverse, the right-hand main amplifier being connected to the output of the left-hand pre-amplifier section; (3) mono-channel, the output circuits of the pre-amplifiers being connected in parallel to the output amplifiers; (4) mono-channel via the left-hand pre-amplifier, the right-hand pre-amplifier being disconnected; in this position the two main amplifiers are connected in parallel. This switch position can be used, for example, for a tuner. It is possible to connect a high-pass filter in series with the left-hand mains amplifier, and a low-pass filter in series with the right-hand main amplifier to obtain a pseudo-stereo effect.

The phase reverse switch for one of the loudspeakers in connected to the secondary of the output transformer of the left-hand channel. In all other respects the stereo amplifier described is identical to the mono-channel amplifier described in the preceding section; the characteristics are also equivalent.

MEASURED RESULTS

VOLTAGES AND CURRENTS

Supply

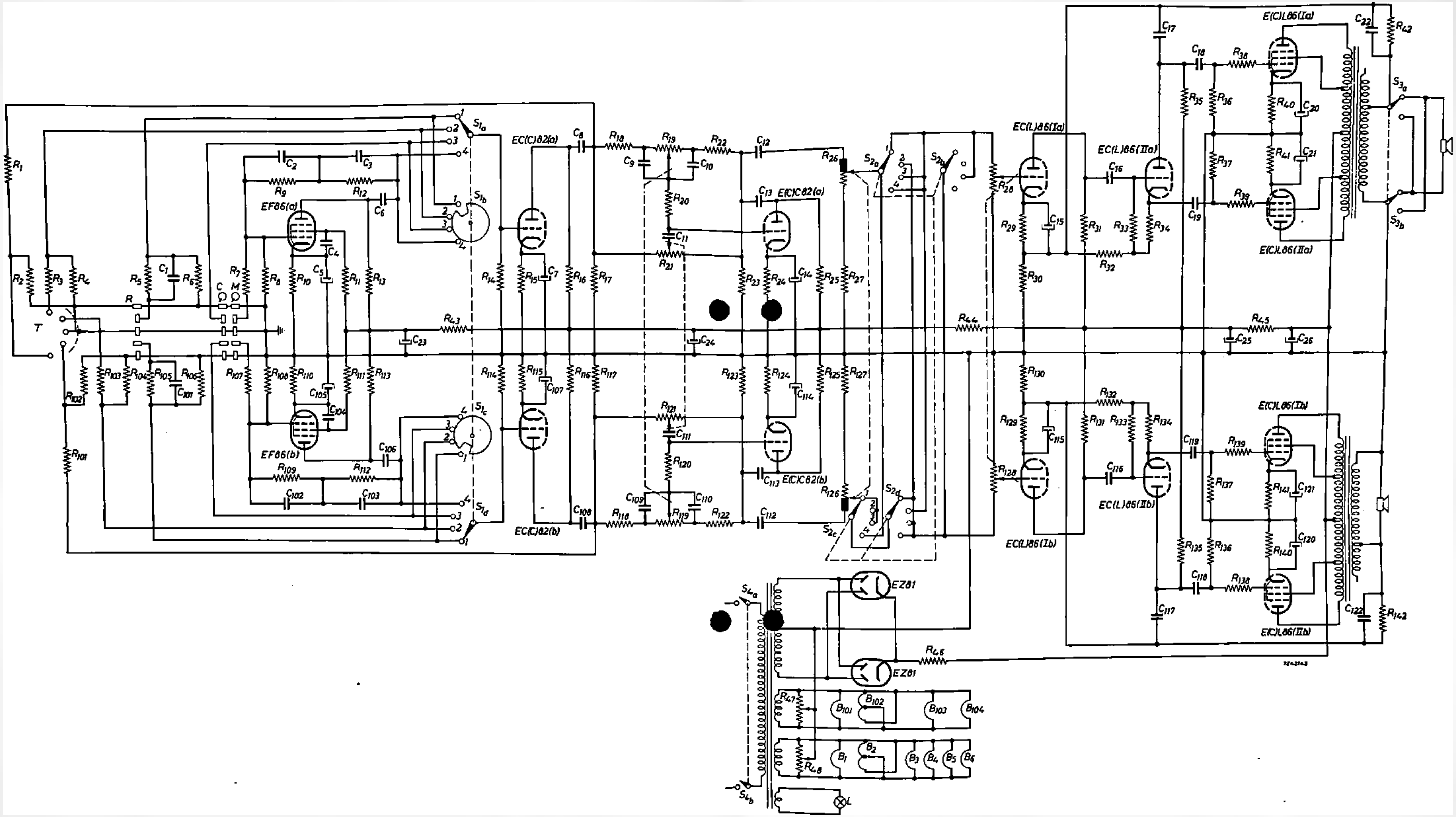
Voltage at

Cathodes EZ81	321 V		
C_{26}	316 V		
C_{25}	300 V	total current drain	150 mA
C_{24}	256 V		
C_{23}	251 V		

ECL86 (four)

pentode sections

anode voltage	310 V	anode current	30 mA
screen-grid voltage	311 V	screen-grid current	4.8 mA
cathode voltage	9.5 V		



EF86(a)
EF86(b)
EC(C)82(a)
EC(C)82(b)
E(C)C82(a)
E(C)C82(b)
EC(L)86(Ia)
EC(L)86(IIa)
EC(L)86(Ib)
EC(L)86(IIb)
E(C)L86(Ia)
E(C)L86(IIa)
E(C)L86(Ib)
E(C)L86(IIb)
EZ81
EZ81

Fig. 24

LIST OF PARTS

R_1, R_{101} = 1 MΩ, ¼ W
R_2, R_{102} = 10 kΩ, ¼ W
R_3, R_{103} = 1 MΩ, ¼ W
R_4, R_{104} = 47 kΩ, ¼ W
R_5, R_{105} = 820 kΩ, ¼ W
R_6, R_{106} = 150 kΩ, ¼ W
R_7, R_{107} = 68 kΩ, ¼ W
R_8, R_{108} = 1 MΩ, ¼ W
R_9, R_{109} = 470 kΩ, ¼ W
R_{10}, R_{110} = 2.2 kΩ, ¼ W
R_{11}, R_{111} = 1.2 MΩ, ¼ W
R_{12}, R_{112} = 10 MΩ, ¼ W
R_{13}, R_{113} = 220 kΩ, ¼ W
R_{14}, R_{114} = 1 MΩ, ¼ W
R_{15}, R_{115} = 1.2 kΩ, ¼ W
R_{16}, R_{116} = 47 kΩ, ½ W
R_{17}, R_{117} = 390 kΩ, ¼ W
R_{18}, R_{118} = 100 kΩ, ¼ W
R_{19}, R_{119} = 1 MΩ, tandem carbon potentiometer, lin.
R_{20}, R_{120} = 220 kΩ, ¼ W
R_{21}, R_{121} = 1 MΩ, tandem carbon potentiometer, lin.
R_{22}, R_{122} = 100 kΩ; ¼ W
R_{23}, R_{123} = 390 kΩ, ¼ W
R_{24}, R_{124} = 2.2 kΩ, ¼ W
R_{25}, R_{125} = 100 kΩ, ¼ W
R_{26}, R_{126} = 1 MΩ, balance control
R_{27}, R_{127} = 470 kΩ, ¼ W
R_{28}, R_{128} = 0.5 MΩ, tandem carbon potentiometer, log.
R_{29}, R_{129} = 1.5 MΩ, ¼ W
R_{30}, R_{130} = 120 Ω, ¼ W
R_{31}, R_{131} = 220 kΩ, ¼ W
R_{32}, R_{132} = 15 kΩ, ½ W
R_{33}, R_{133} = 1 MΩ, ¼ W
R_{34}, R_{134} = 1 kΩ, ¼ W
R_{35}, R_{135} = 15 kΩ, ½ W
R_{36}, R_{136} = 470 kΩ, ¼ W
R_{37}, R_{137} = 470 kΩ, ¼ W
R_{38}, R_{138} = 5.6 kΩ, ¼ W
R_{39}, R_{139} = 5.6 kΩ, ¼ W
R_{40}, R_{140} = 270 Ω, ½ W
R_{41}, R_{141} = 270 Ω, ½ W
R_{42}, R_{142} = 2.2 kΩ, ¼ W, 7 Ω matching
3.3 kΩ, ¼ W, 14 Ω matching
R_{43} = 1 kΩ, ½ W
R_{44} = 3.9 kΩ, 1 W
R_{45} = 2.7 kΩ, ½ W
R_{46} = 39 Ω, 5 W, wire wound
R_{47} = 200 Ω, wire-wound trimming potentiometer
R_{48} = 200 Ω, wire-wound trimming potentiometer

C_1, C_{101} = 10 pF, ceramic
C_2, C_{102} = 200 pF, ceramic 2 % tolerances
C_3, C_{103} = 560 pF, ceramic, 2 % tolerances
C_4, C_{104} = 100 nF, polyester, 400 V wkg.
C_5, C_{105} = 100 μF, electrolytic, 4 V wkg.
C_6, C_{106} = 22 nF, polyester, 400 V wkg.
C_7, C_{107} = 100 μF, electrolytic, 4 V wkg.
C_8, C_{108} = 220 nF, polyester, 400 V wkg.
C_9, C_{109} = 3.3 nF, ceramic, 10 % tolerances
C_{10}, C_{110} = 3.3 nF, ceramic, 10 % tolerances
C_{11}, C_{111} = 100 pF, ceramic, 10 % tolerances
C_{12}, C_{112} = 100 nF, polyester, 125 V wkg.
C_{13}, C_{113} = 100 nF, polyester, 400 V wkg.
C_{14}, C_{114} = 100 μF, electrolytic, 4 V wkg.
C_{15}, C_{115} = 25 μF, electrolytic, 25 V wkg.
C_{16}, C_{116} = 100 nF, polyester, 400 V wkg.
C_{17}, C_{117} = 150 pF, ceramic, 10 % tolerances
C_{18}, C_{118} = 220 nF, polyester, 400 V wkg.
C_{19}, C_{119} = 220 nF, polyester, 400 V wkg.
C_{20}, C_{120} = 100 μF, electrolytic, 16 V wkg.
C_{21}, C_{121} = 100 μF, electrolytic, 16 V wkg.
C_{22}, C_{122} = 680 pF, ceramic, 10 %, 7 Ω matching
390 pF, ceramic, 10 %, 14 Ω matching
C_{23} = 16 μF, electrolytic, 350 V wkg.
$\left.\begin{matrix} C_{24} \\ C_{25} \\ C_{26} \end{matrix}\right\}$ = 3 × 50 μF, electrolytic, 350 V wkg.

Transformers

T_1, T_{101} = output transformer type AD9058
T_2 = supply transformer type 919/290 × 200

triode sections
IIa, IIb

anode voltage	273 V	anode current	1.7 mA
cathode voltage	28 V		

Ia, Ib

anode voltage	150 V	anode current	0.7 mA
cathode voltage	1.3 V		

ECC82 (two)
second section

anode voltage	87 V	anode current	1.7 mA
cathode voltage	3.7 V		

first section

anode voltage	108 V	anode current	3.2 mA
cathode voltage	3.8 V		

EF86 (two)

anode voltage	92 V	anode current	0.72 mA
screen-grid voltage	83 V	screen-grid current	0.14 mA
cathode voltage	1.9 V		

FREQUENCY RESPONSE

The frequency response is identical to that of the mono-channel amplifier described in the preceding section; the curves for the "flat" position of the tone controls and with the maximum bass boost and cut, and with maximum treble cut and boost are plotted in Fig.18.

POWER RESPONSE

The power response is identical to that of the mono-channel amplifier (see Fig.19).

HARMONIC DISTORTION AND INTERMODULATION DISTORTION

The distortion figures are identical to those of the amplifier described in the preceding section; the curves are given in Figs 20 and 21 respectively.

PHASE SHIFT

The phase shift is identical to that of the amplifier described in the preceding section; the curve is given in Fig.22.

R.I.A.A. CORRECTION

The correction characteristics of the pre-stages are identical to those of the amplifier described in the preceding section, (see Fig.23).

CROSS TALK

Cross talk, measured at a frequency of 1 kc/s, is −41 dB for each channel.

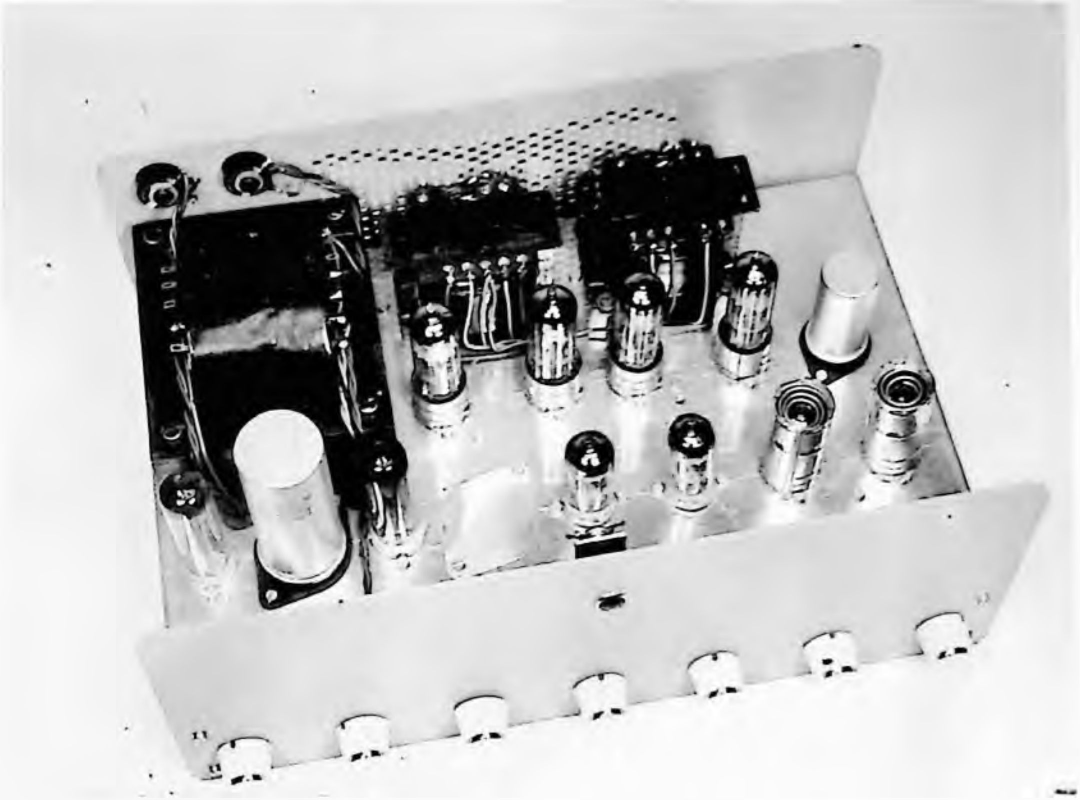


Fig.25. Experimental chassis of the stereophonic Hi-Fi amplifier with only four tubes per channel. With closed cabinet the temperature became too high after prolonged use. After two rectangular apertures covered with wire mesh had been made in the front panel, the temperature remained within permissible limits. The control knobs from left to right are: mains switch, function switch, volume control, balance control, treble control, bass control and the selector switch. The phase reverse switch is mounted at the back of the chassis.

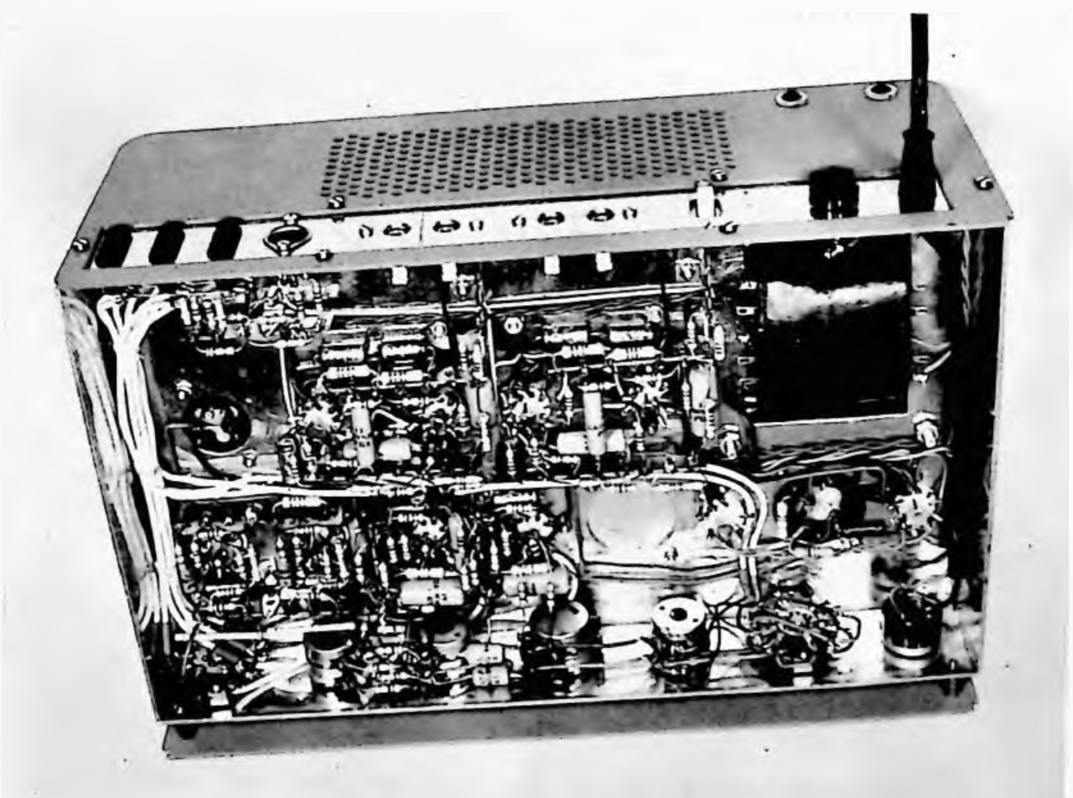


Fig.26. Bottom view of the stereophonic Hi-Fi amplifier.

The information given in this Bulletin does not imply a licence under any patent.

Printed in Holland

25/021/D/E/10-'63