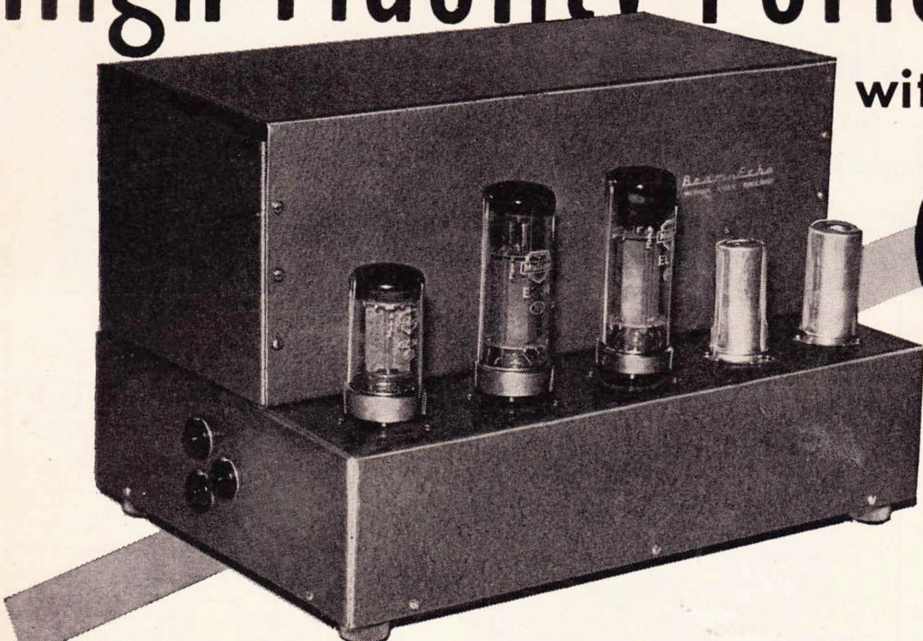
High Fidelity Performance with Mullard's 520 Circuit



Over-all view of power amplifier. The three fuses are mounted on the left flange while the "on-off" switch appears on the right flange. The large housing (which is vented at top and bottom) directly behind the tubes covers the output and power transformers and filter choke. The other components are mounted below the chassis.

By E. J. PORTO*

The original British-designed power amplifier was conservatively rated at 20 watts. Actual tests showed an output of 36 watts with .2% harmonic distortion. Maximum output is with .3 volt input.

CONSIDERABLE international attention has been focused on a new audio output pentode, the EL34, recently introduced in England by *Mullard Ltd.*, in view of the many American power amplifier designs based around this new tube. The circuit described in this article is basically an "Ultra-Linear" design that was originally worked up by *Mullard Ltd.* and published in *"Wireless World."* According to published data, it was rated at 20 watts with a total harmonic distortion of .05% at rated output. Actual tests by American standards resulted in a rather surprising performance in that, instead of 20 watts output, we were able to obtain up to 36 watts with a total harmonic distortion of .2%.

Before going into the actual details of this power amplifier, let us review the basic requirements of amplifier designs that are important considerations for high-fidelity reproduction. Briefly, they are as follows:

1. Low harmonic and intermodulation distortion
2. Linear frequency response throughout the audible range
3. Good response to transient signals
4. Low phase shift
5. Low hum and noise level
6. Enough power output to allow peaks to be reproduced without overloading
7. Low output resistance to provide electrical damping for the loudspeaker system
8. Stability under feedback conditions

Amplifier Designs

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

The maximum power output and the corresponding distortion vary appreciably with the value of load impedance. 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 plate dissipation of 25 watts.

Increasing interest is being shown in circuits employing distributed loading ("Ultra-Linear" operation) of the output stage (Fig. 1). These circuits apply negative feedback in the output stage itself. In the simplest form, the screen grids of the output tubes are fed from taps on the primary of the output transformer. The stage can be considered as one in which negative feedback is 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 per-

TABLE 1.
THE MULLARD EL34 TUBE UNDER VARIOUS OPERATING CONDITIONS

MODE OF OPERATION	OPERATING CONDITIONS					IM DISTORTION (in per-cent at)		
	E_p (volts)	E_{g2} (volts)	R_k (ohms)	Impedance (P-P, ohms)	R_{g2} (ohms)	10 w.	14 w.	36 w.
Triode-connected	400		470 (each)	10K		.4	.6	....
Distributed-load ("Ultra-Linear")	400	400	470 (each)	6.6K	1000 (each)	.5	.6	.8
Pentode-connected (push-pull)	330	330	130 (common)	3.4K	470 (common)	1.5	2.0	4.0

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centage of the primary winding common to plate 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 used with greatly reduced distortion, while 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, therefore, be used with pentodes of the 25-watt class in high-quality amplifiers designed for power outputs well in excess of 30 watts, the over-all power efficiency being much greater than with triode operation.

Table 1 is a comparison of triode, pentode, and distributed-load operation for the EL34. For tubes of the EL34 type, comparison with triode operation is of most interest. It will be seen that distributed-load operation enables the power-handling capacity to be more than double that possible with triode operation while, 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 to 1 the distortion level is comparable to triode conditions, it has been found that appreciable improvement is obtained at higher power outputs if the common winding ratio is further increased.

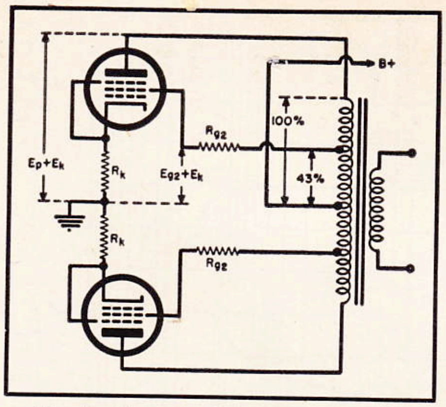


Fig. 1. Theoretical design for "Ultra-Linear" circuitry used in amplifier. The percentage figure is turns ratio.

From the figures of 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 a closer approach to Class A triode operation, variations in plate 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 the load impedance. With a primary tap

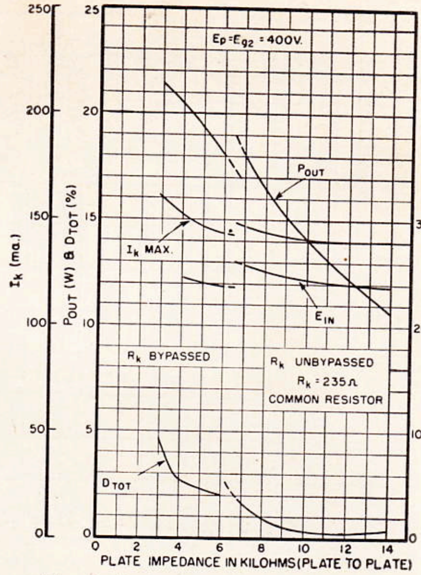


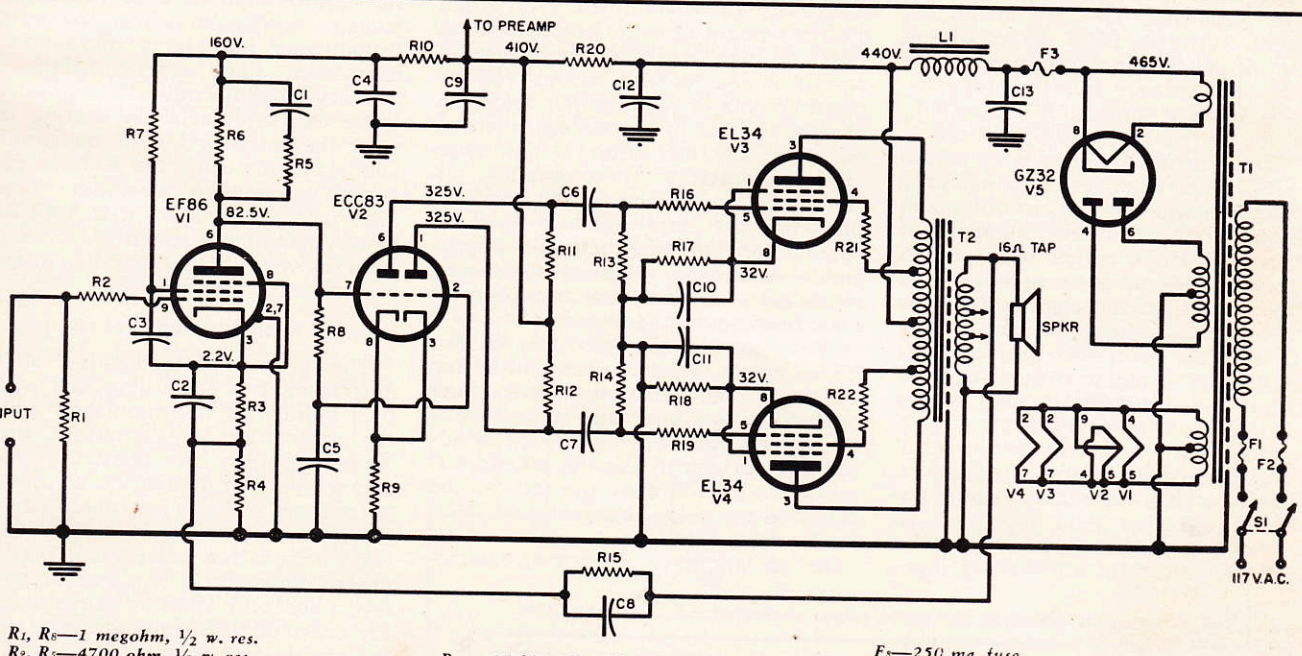
Fig. 2. Performance curves of two triode-connected EL34 tubes in push-pull. Refer to text for complete discussion.

of about 40% of the turns, little change in performance is produced by a change in the plate-to-plate load impedance of 6000 to 9000 ohms. In addition the output impedance of the stage is still further reduced by the use of the larger common winding ratio.

Circuit Arrangements

The next-to-the-last-stage of the amplifier must be capable of providing a

Fig. 3. Schematic of Mullard 520 amplifier. All parts are available at local parts jobbers. Maximum current drain for preamp is 40 ma.



R_1, R_8—1 megohm, ½ w. res.
R_2, R_5—4700 ohm, ½ w. res.
R_3, R_{16}, R_{19}—2200 ohm, ½ w. res.
R_4—100 ohm, ½ w. res.
R_6—100,000 ohm, ½ w. res.
R_7—390,000 ohm, ½ w. res.
R_9—8200 ohm, ½ w. res.
R_{10}—270,000 ohm, ½ w. res.
R_{11}, R_{12}—180,000 ohm, ½ w. res. (Matched ±5%, R_{12} to be greater than R_{11})
R_{13}, R_{14}—470,000 ohm, ½ w. res. (Matched ±5%)
R_{15}—8200 ohm, ½ w. res. ±5% (for 16-ohm load)
R_{17}, R_{18}—470 ohm, 5 w. wirewound res. ±5% (critical value)
R_{20}—15,000 ohm, ½ w, res.
R_{21}, R_{22}—1000 ohm, ½ w. res.
C_1—47 μμfd. disc ceramic capacitor
C_2—50 μfd., 12 v. elec. capacitor
C_3—.05 μfd., 400 v. capacitor
C_4, C_9—8 μfd., 450 v. elec. capacitor
C_5—.25 μfd., 400 v. capacitor
C_6, C_7—.05 μfd., 400 v. capacitor
C_8—220 μμfd. ceramic capacitor (for 16-ohm load)
C_{10}, C_{11}—50 μfd., 50 v. elec. capacitor
C_{12}, C_{13}—8 μfd., 500 v. elec. capacitor
L_1—8 hy, 180 ma., 145 ohm filter choke (Thordarson T-20-C-54 or UTC H-62)
F_1, F_2—2 amp fuse
F_3—250 ma. fuse
S_1—D.p.s.t. switch (Power "on-off")
T_1—Power trans. 400-0-400 v. @ 200 ma.; 5 v. @ 3 amps.; 6.3 v. c.t. @ 5 amps. (Stancor PM-8412 or equiv.)
T_2—Output trans. (Any of the following may be used: Acro Products Company TO-300, 6600 ohms p-to-p, 4-8-16 ohms; Chicago-Standard Transformer Corp. A-8072, 7600 ohms p-to-p, 4-8-16 ohms; Dyna Company A-420. 6600 ohms p-to-p, 8-16 ohms; Partridge P3878, 6600 ohms p-to-p, 4-16 ohms)
V_1—EF86 tube (Mullard)
V_2—ECC83 tube (Mullard)
V_3, V_4—EL34 tube (Mullard)
V_5—GZ32 or GZ34 tube (Mullard)

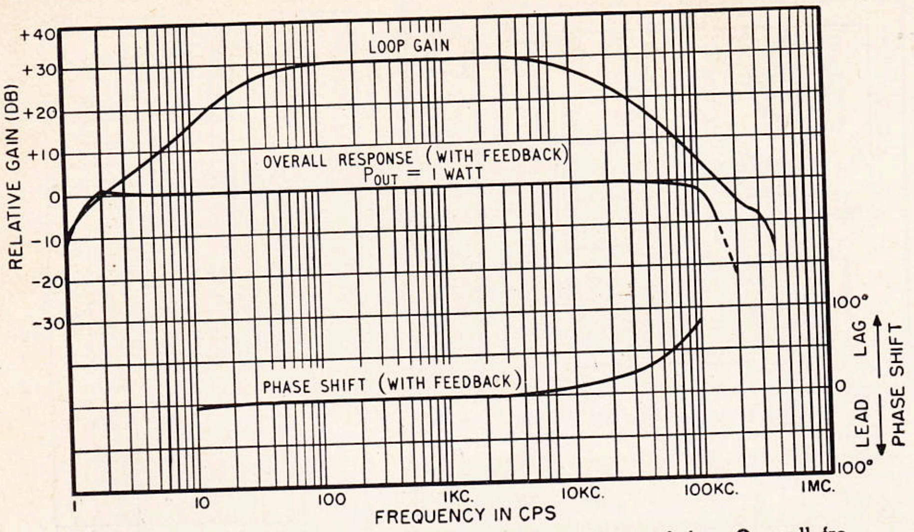


Fig. 4. Loop gain, frequency response, and phase characteristics. Over-all frequency response at 36 watt operation is flat, 30 to 20,000 cycles-per-second.

TABLE 2.
SUMMARY OF PERFORMANCE CHARACTERISTICS OF THE POWER AMPLIFIER

Power output:	36 watts; 30 to 20,000 cps
Frequency response: (at 36 watts)	within 1 db from 20 to 20,000 cps
Harmonic distortion: (at 400 cps)	.05% at 20 watts, .2% at 36 watts
IM distortion: (40 to 10,000 cps, 4:1 ratio)	.8% with peak corresponding to 36 watts sine-wave power
Hum and noise:	−89 db (relative to 36 watts)
Sensitivity:	.3 volt for 36 watt output
Damping factor:	50

well balanced push-pull drive of adequate amplitude and low distortion content. With the EL34 the maximum drive voltage required is approximately 2 x 25 volts r.m.s. Input voltage requirements are similar for triode, pentode, or distributed-load operation.

Bearing in mind the need to insure stability when feedback is applied over the whole amplifier, the circuit should contain the minimum number of stages in order to reduce phase shifts. If the function of phase splitting and amplification can be combined in the next-to-the-last-stage, so much the better. This can be conveniently achieved by using a cathode-coupled form of phase splitter. 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 gain of about 25 times can be obtained simultaneously. This, combined with a preceding high-gain stage, enables a high over-all sensitivity to be obtained, even when a large amount of negative feedback is used. A high sensitivity in the main amplifier enables the output voltage requirements of preamplifier and tone control circuits to be reduced, thereby enabling low distortion to be more easily achieved in these circuits. It should be remembered that circuits preceding the main amplifier must be capable of handling, without appreciable distortion, voltages which are much greater than those necessary to load the amplifier fully.

With the use of such tubes as the EF86, which is particularly suited 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 100 to 300 millivolts for 36-watt output can be achieved while keeping hum and noise levels extremely low.

In an amplifier employing single-loop feedback from output/input, instability will occur if the loop gain exceeds unity at frequencies for which the total phase shift around 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°.

It is, therefore, necessary to control the amplifier characteristics over a frequency range greatly in excess of the designed working band. As the degree of feedback increases, control becomes more difficult and is usually limited by the leakage inductance, self-capacitance, and primary inductance of the output transformer. It is quite difficult in practice to provide a constant and high level of feedback over the whole audible 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. The *Mullard* 520 circuit is especially designed and engineered to maintain a constant degree of feedback throughout the audible range.

The performance of any high-quality amplifier is, ultimately, dependent on the quality of the output transformer. The use of distributed-load conditions does not modify the essential requirement 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.

We can summarize by stating that with the introduction of distributed-load operation using the *Mullard* EL34 output pentode we can design efficient high-quality amplifiers with very high power handling capacities to reproduce the widest dynamic range of modern program sources.

Construction Details

The plate-to-plate loading of the output stage is 6600 ohms and with a feed voltage of approximately 440 at the center-tap of the output transformer primary the combined anode and screen-grid dissipation of the output tubes is 28 watts per tube. With the particular screen-grid-to-plate-turns ratio used, it has been found that improved linearity is obtained at power levels above 15 watts when resistors on the order of 1000 ohms 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 primarily because of the uniform characteristics of the

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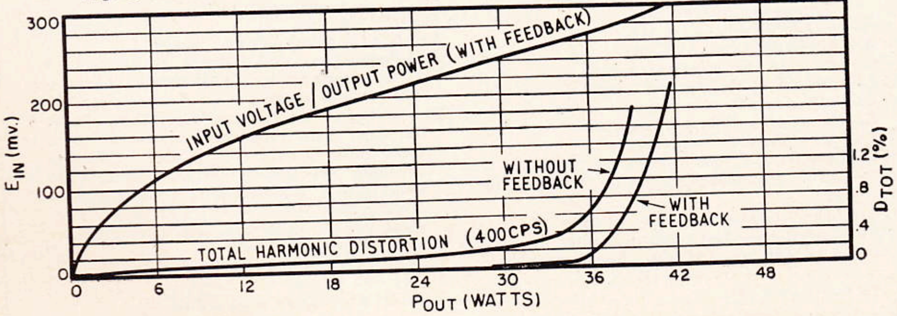
Fig. 5. Harmonic distortion and input/output characteristics of the amplifier.



Mullard's 520 Circuit

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EL34. It is necessary, in this type of output stage, that the cathodes be bypassed to ground even when a common cathode resistor is used.

The power supply is conventional and uses a *Mullard* GZ32 or GZ34 indirectly-heated, full-wave rectifier with capacitor input filter.

The driver stage uses a *Mullard* ECC83 twin-triode and fulfills the combined function of phase splitter and driver amplifier. It is of the cathode-coupled type and enables a high degree of push-pull balance to be obtained.

The first stage is a high-gain pentode voltage amplifier using an EF86 low-hum pentode. High-stability carbon resistors are used in plate, 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.

Despite 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 this circuit. 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. The loop gain, overall frequency response, and phase shift characteristics of the whole amplifier are shown in Fig. 4.

The harmonic distortion of this amplifier at 400 cps, measured without feedback under resistive load conditions, is shown in Fig. 5. The distortion curve towards the overload point is also shown for feedback conditions. At the 20-watt level the distortion level without feedback is well below 1% and with feedback applied falls to below 0.05%. Harmonic distortion at 400 cps reaches 0.2% at approximately 36 watts output. The loop gain characteristics are such that at least 20 db feedback is maintained from 15 to 25,000 cps.

Measurement of intermodulation products has been made, using a carrier frequency of 10,000 cps, and a modulating frequency of 40 cps, with a ratio of 40 to 10,000 cps amplitudes of 4:1. With the combined peak amplitude of the mixed output at a level corresponding to the peak sine wave amplitude at 36 watts r.m.s. power, intermodulation products expressed in r.m.s. terms totaled 0.8% of the 10,000 cps carrier amplitude.

The sensitivity of the amplifier is approximately 0.3 volt for 36 watts output. The background level in this amplifier was 89 db below at 36 watts, measured with a source resistance of 10,000 ohms. —30—