

An A.F. Power Amplifier with Crossover Feedback

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The design of conventional a.f. power amplifiers for high-fidelity reproduction is inadequate for many laboratory uses. In particular the distortion is frequently excessive over part of the frequency spectrum, and stability is not often maintained on capacitive loads. This article describes the design philosophy and performance of an amplifier designed for laboratory use and having a much better specification than that which is customarily accepted.

Full rated power is obtainable over the whole audio frequency range at distortion levels of less than 0.1 per cent. In addition the amplifier is unconditionally stable for all load values and has good overload recovery performance.

(Voir page 847 pour le résumé en français: Zusammenfassung in deutscher Sprache auf Seite 854)

LABORATORY power amplifiers have design requirements that are considerably more stringent than those of power amplifiers feeding fixed loads. Full output current may be required into near short-circuit loads, often at

at high frequencies due to the Miller effect in the output valves.

The circuit finally used is shown in Fig. 1. This is a pentode long-tailed pair and uses frame-grid valves. Ample

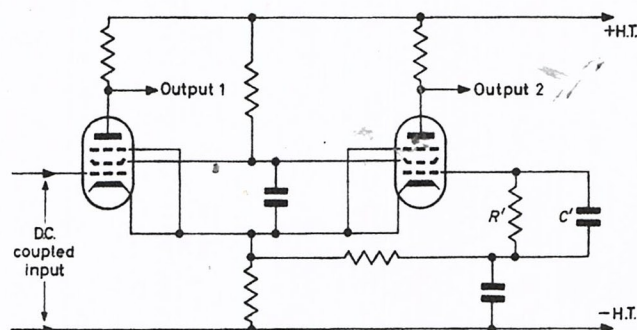


Fig. 1. Basic phase-splitter circuit

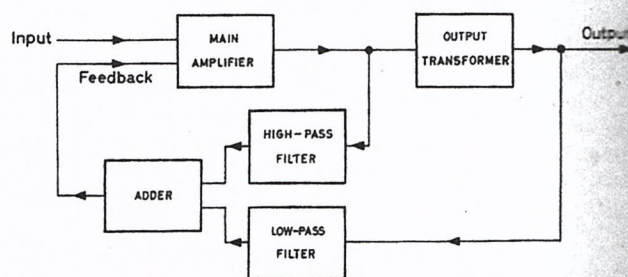


Fig. 2. Crossover-feedback system

very high frequencies. In addition the stability must be exceptionally good for the amplifier to be capable of operating into pure capacitive loads. If a very low distortion is also required over the audio frequency range, then the design problem becomes very difficult. Due to this it was decided to use valves rather than transistors, particularly as valves are far more robust when driving active loads or those possessing high energy storage.

The amplifier will need a large amount of overall feedback to reduce distortion and the output impedance to low levels. This in turn gives rise to instability problems so it was considered essential that all the amplifier stages were designed with the maximum possible bandwidth. In fact the design problems are very similar to those in video amplifiers.

The first amplifying stage must possess low noise and microphony as well as a wide bandwidth so the cascode circuit became the obvious choice. In order that adequate gain could be obtained with wide bandwidth a frame-grid valve was used.

The phase-inverter presented something of a problem. A high gain was required as well as a low output impedance and fairly low input impedance. The author had previously used a triode-pentode phase-splitter¹, but this proved to give inadequate drive and gain when used with low values of anode resistor. The low output impedance required (12k Ω) is necessary to avoid spurious gain losses

drive can be obtained for the output valves along with quite high gain and low input capacitance. The circuit has the added advantage of the long-tailed-pair configuration in being suitable for d.c. coupling to the previous stage. This removes one l.f. time-constant with consequent improvement in l.f. stability.

The RC network R' and C' is included in the grid circuit of the grounded-grid section so as to equalize the a.c. impedances to the grids of the two sections. This greatly improves the overload performance due to the symmetrical characteristics that result.

The output valves are operated in the Blumlein 'ultra-linear' connexion so as to give minimum distortion. The capacitance between screen-grid and control-grid then gives rise to the high input capacitance mentioned previously. The output transformer must be of multi-section design to give both maximum bandwidth and good primary balancing at high audio frequencies. This latter requirement is more stringent in the tapped-load configuration used, as the screen tapping points must remain accurate at very high frequencies.

The bandwidth of the previous circuits can be made to extend up to the megacycle per second region, so the output transformer is obviously the limiting factor. If pure capacitive loads are placed on output transformers and the overall Nyquist plot produced, then it immediately becomes obvious that the secondary phase at very high frequencies can shift large amounts and still give

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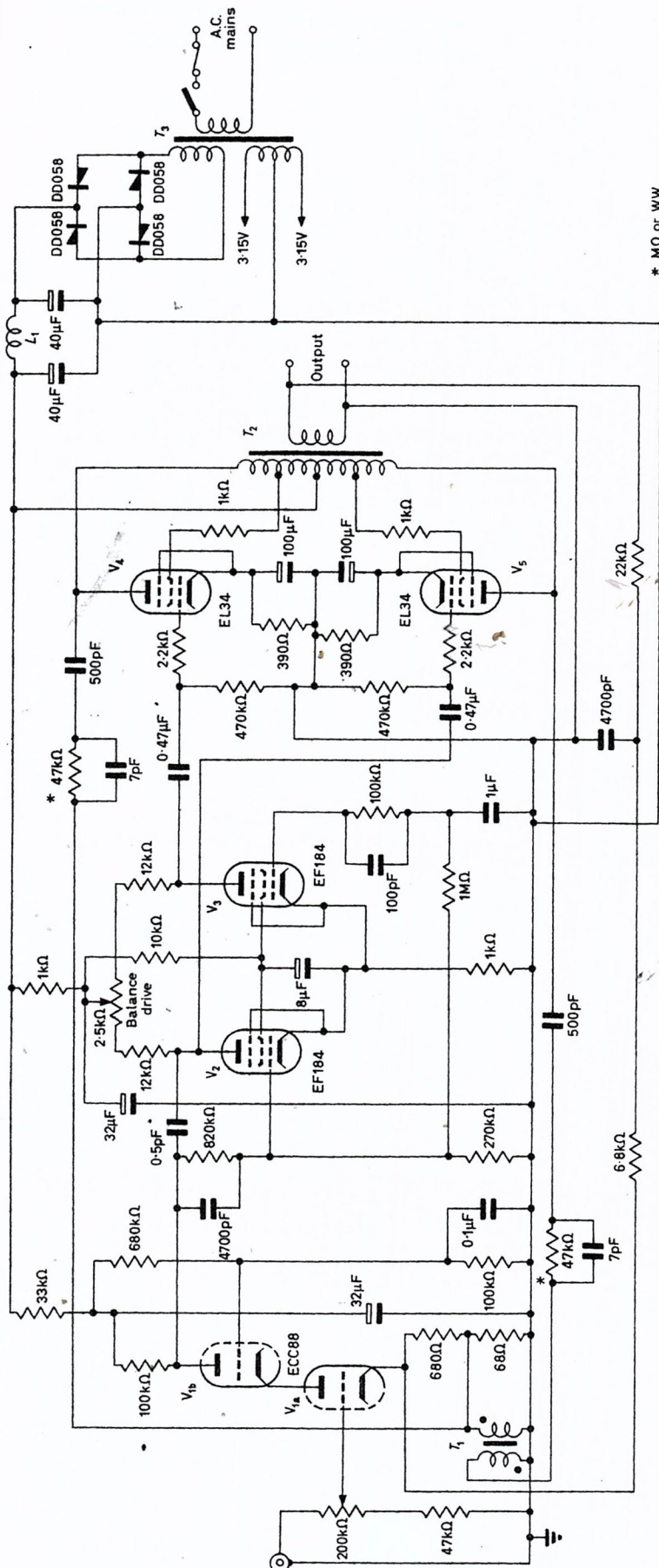


Fig. 3. The complete amplifier

considerable output. The means of overcoming this defect was suggested by Mr. D. Hafner of Dynaco Inc. Philadelphia. This was to the effect that if the feedback is taken from a separate transformer fed from the output transformer primary, then the stability is considerably improved under capacitive load conditions.

After some thought the reason became clear that the maximum phase-shift on the transformer primary can be only 90° as this is an impedance function. The secondary phase-shift can, however, have no final limits as this is a transfer-function comprising many elements.

Secondary feedback is necessary at low frequencies to reduce the iron distortion due to the transformer core. At high frequencies there is no longer this restriction so the feedback can be taken from the transformer primary. The crossover of feedback from primary to secondary can be made by complementary filters as shown in Fig. 2.

Unfortunately, the primary of the output transformer is driven in push-pull. The h.f. feedback must be derived from both anodes or the asymmetry results in high h.f. distortion and instability under peak drive conditions. After several experiments the best performance was obtained by using a bifilar mixing transformer to add the two h.f. anode voltages. Due to the crossover frequency being towards the top end of the audio spectrum, the transformer can be very small and iron distortion negligible.

Simple RC filter circuits are used for the crossover as these are found to be quite adequate.

Comparison of the amplifier performance with all the feedback from the secondary, with that of the crossover feedback, showed the crossover system to be far superior. Under resistive load conditions the amplifier stability was much improved due to the reduced h.f. phase-shift in the feedback loop. On open-circuit and capacitive loads the effect was even more marked as the load had then no damping effect on the transformer resonances.

The high gain with stability made it possible to utilize very high feedback values (40dB) and at the same time avoid the necessity of phase-advance stabilization of such magnitude that the amplifier response and rise-time suffered.

In addition, the effective bandwidth of the feedback over the output stage is so high that the stabilizing dominant lag of the whole circuit can be a simple RC time-constant starting at the extreme edge of the audio frequency range. This avoidance of a step-network inside the audio frequency spectrum prevents the falling feedback, and consequent

distortion rise, that is such a feature of normal a.f. amplifiers.

The circuit is therefore much more 'designable' in that the deficiencies in the output transformer are removed from the feedback path. Production variations in h.f. resonances will therefore only have a small effect on the

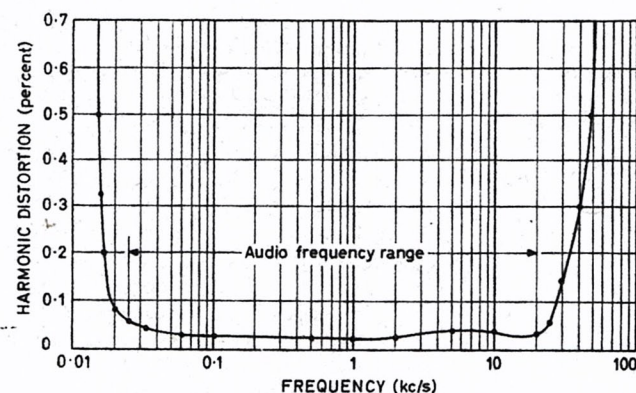


Fig. 4. Harmonic distortion of complete amplifier

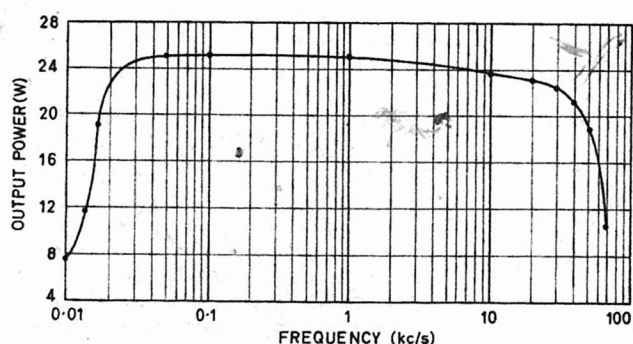


Fig. 5. Power output at fixed distortion level

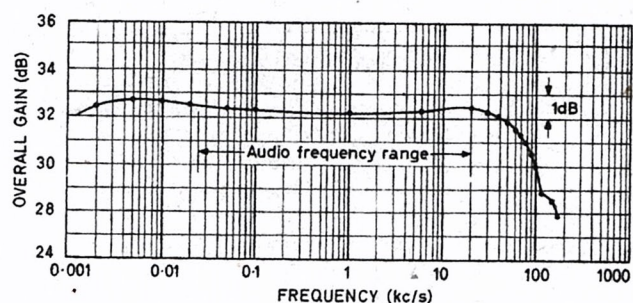
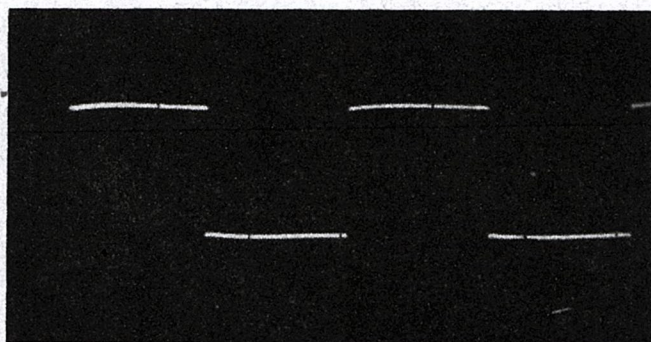


Fig. 6 (above). Overall frequency response

Fig. 7 (below). Amplifier response to 50c/s square-wave input, 16Ω resistive load



transient performance of the amplifier as a whole. Owing to the increased feedback that can be applied, it is now possible to obtain much better performance from amplifiers with output transformers.

The circuit of the complete amplifier is shown in Fig. 3 with the component values used in a practical circuit. The performance of the amplifier at full rated power output can be seen from Fig. 4, full output at less than 0.1 per cent distortion being available from 19c/s to 26kc/s.

Where very low distortion is not important, the amplifier will deliver considerably more power over a wide frequency range. Fig. 5 shows the performance obtained at a fixed distortion level of 1 per cent in the output.

Due to the large amount of feedback the amplitude response would be expected to be very flat. This is in fact the case as can be seen from Fig. 6, the audio range being covered with a gain tolerance of ± 0.1 dB. Beyond this region the initial rate of gain fall is low to prevent ringing on transients. Some idea of the transient performance can be obtained from the square-wave output photographs shown in Figs. 7, 8 and 9.

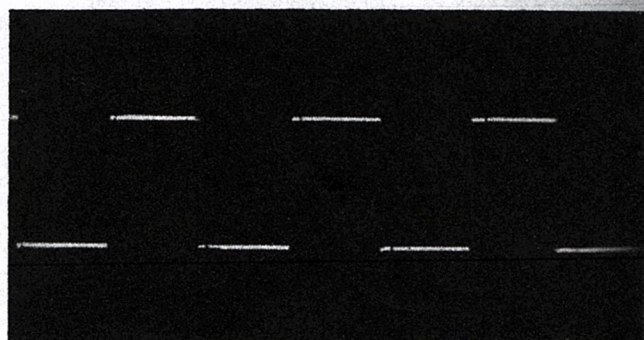


Fig. 8. Response to 1000c/s square-wave input, 16Ω resistive load

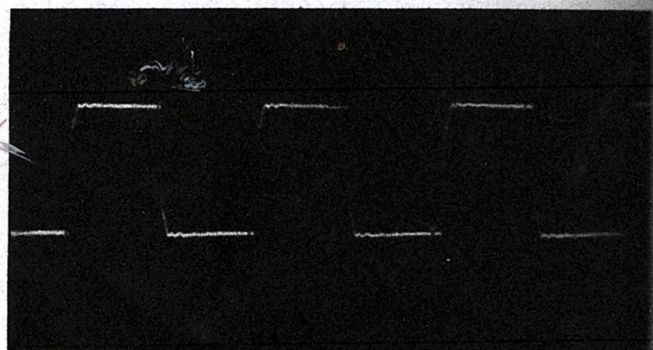
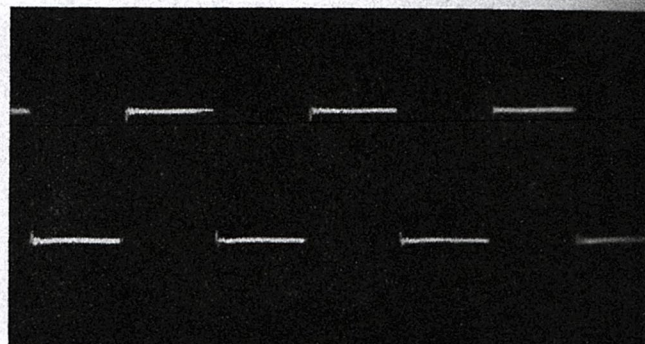
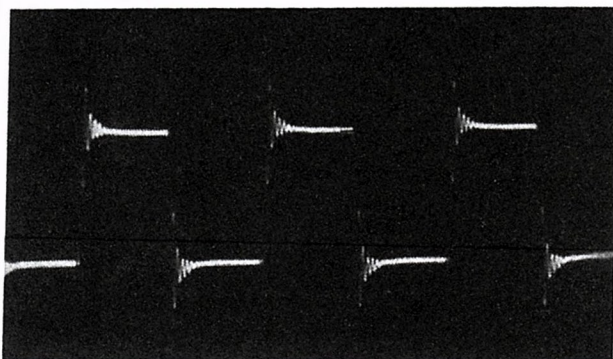


Fig. 9 (above). Response to 10kc/s square-wave input 16Ω resistive load

Fig. 10 (below). Response to 5kc/s square wave, load of 16Ω resistive in parallel with 0.05μF capacitance





11. Response to 5kc/s square wave, load of 0.05 μ F pure capacitance

The stability on capacitive loads was expected to be good due to the h.f. feedback being taken from the

transformer primary. This is the case as is shown in Figs. 10 and 11, the capacitive load being chosen to give the maximum overshoot to the square wave.

Other details of the amplifier are:

Main loop feedback	40dB
Rated power output	15W
Input for rated power output	360mV
Intermodulation distortion (S.M.P.T.E.)	0.055 per cent
Hum and noise (Unweighted)	80dB on full output

Unconditionally stable for all conditions of drive and load. The feedback system is the subject of a patent.

Acknowledgment

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REFERENCE

1. BAILEY, A. R. New Phase-Splitter. *Wireless World*. 68, 411 (1962).