

In the first part of this article, I covered some of the developments in the design of transistor audio power amplifiers from the commercial introduction of transistors to about 1975, by which date some competently engineered designs had been produced.

A fair proportion of the designs produced at the end of this period were capable of a performance which would, to the ear of an unprejudiced listener, at least equal most of the previous generation of valve operated equipments and were also more compact, cooler running and of substantially greater potential output power.

However, design mistakes had been made and some units having a relatively poor acoustic performance had been produced, particularly during the earlier years of this period. Although there was a better understanding of the requirements for audio power amplifiers, some relatively indifferent designs were still being offered. Even in the case of the good designs, some residual intrinsic problems remained.

There was the need to ensure that the quiescent current of the output transistors, in the typical class AB output mode, was correctly set on manufacture and remained correct during the life of the equipment. There was also the problem of time lag in the thermal compensation circuitry, which could mean that the quiescent current setting could be in error at the onset of a burst of high output power or in the period immediately following it.

In addition, the relatively high amounts of negative feedback normally employed in these designs could cause sporadic malfunction when used with loudspeakers which had awkward impedance characteristics, making the amplifiers prone to "hard" clipping on signal overload. This effect would effectively require a larger transistor amplifier to deliver the same amount of apparently undistorted output power to the speaker than would have been the case with a valve design.

Design trends

At this time, three separate design trends began to emerge, of which the most explicable, from the engineering point of view, was that of removing or

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John Linsley Hood
continues his
examination of the
evolution of transistor
audio power
amplifiers with a look
at methods of
reducing
residual defects



lessening the residual effects of transistor designs, such as the non-linearity of the class AB push-pull output stage; the variability of, or the need to pre-set some chosen value for, the output stage quiescent current; and, in earlier designs, the need to use high levels of negative feedback to achieve acceptably low levels of harmonic distortion.

The second line of development, pursued with great vigour in Japan, was that of seeking needlessly high levels of steady/state linearity and, in the USA, equally unnecessary – in normal domestic use – levels of output power and bandwidth.

This technical development was mainly spurred on by the belief of the 'man in the street' that he needed high output powers and that large bandwidths and very low THD levels were synonymous with perceived sound quality. The same reasoning would lead to the argument that it was the difference in engine capacity which made a 220BHP Mercedes a quieter and more comfortable car than a Citroën 2CV.

Few lay enthusiasts would accept that they could not hear any difference between two units whose only dissimilarity was that between 0.005% THD and 0.05% THD at any point within the audio pass-band; or that, in the majority of cases, their needs could probably be comfortably met by 5W of peak audio output power.

The third design trend was a wholehearted, and perhaps cynical adoption of pseudo-scientific ideas offered by

eccentric innovators on the fringes of the 'audiophile' fraternity, particularly when these ideas were applauded by the quasi-technical 'hi-fi' press. The hope was, one supposes, that equipment designed in accordance with these ideas might be applauded by the pundits and so become the acoustic criterion by which all other equipment would be judged.

As an engineer, I am more in sympathy with the first of these design trends because their targets are clear and their aims are explicable.

Circuit developments

Blomley. One of the first serious attempts to overcome the difficulties of defining and maintaining the correct quiescent current setting for the output transistors was that due to Blomley¹, who proposed that crossover distortion should be avoided by arranging that the output transistors were biased permanently to a point at the beginning of the linear part of their V_{BE}/I_C characteristics. The preceding part of the circuit, of which the whole is shown in schematic form in Fig. 1, is then designed to present the output stage with an input signal divided into two halves by means of a preceding switching stage, so that the output devices are only required to provide an output current which increases from the pre-set quiescent level.

This is effectively a class B driver stage, but the small-signal switching stage can do this job much more accurately and cleanly than the power output devices could ever do and the small-signal switching stage is unlikely to suffer from thermal drift as a result of the total power output of the amplifier.

Although the idea is sensible and practical, no commercial unit based on this system has been offered.

Error feedforward. This method of reducing system distortion was envisaged by Black², the inventor of the negative-feedback technique, though at the time of its invention adequate components were not available and it was neglected.

The method was resurrected by Sandman³ in an interesting contribution in which he showed two practical examples of amplifiers in which distortion was reduced by feeding forward an error signal to the loudspeaker; these

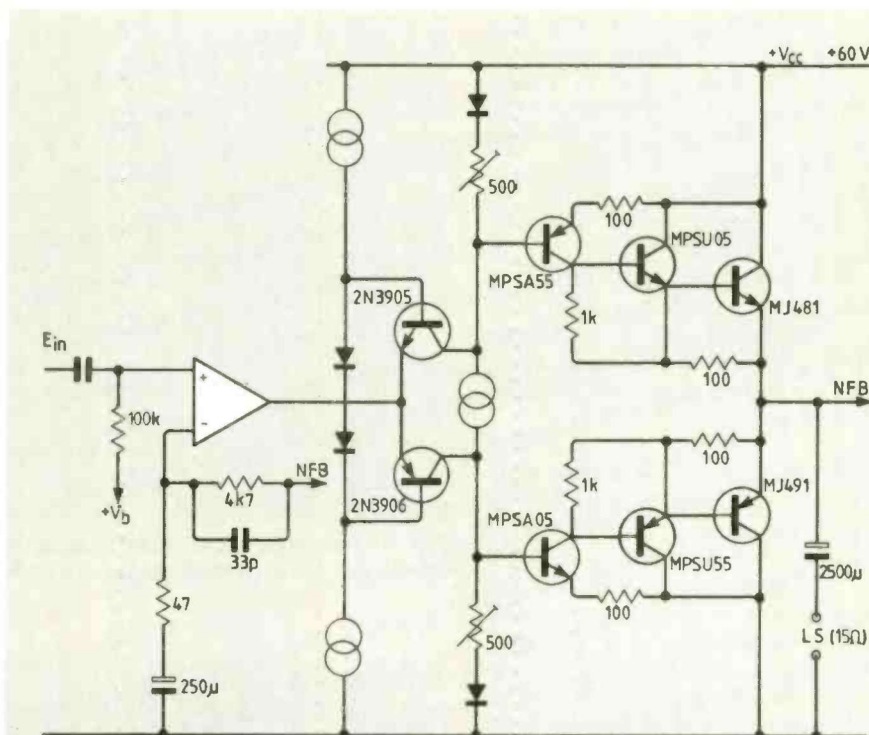


Fig. 1. Simplified Blomley 30W amplifier, with a small-signal switching stage doing the job of a class B output stage.

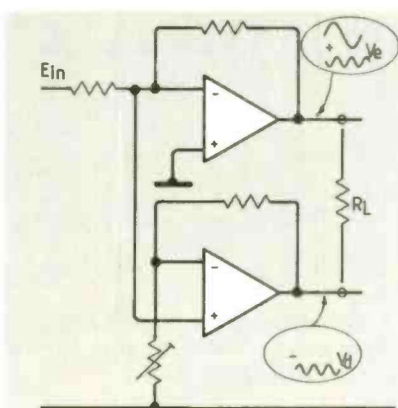


Fig. 2. Distortion correction by error take-off, due to Sandman.

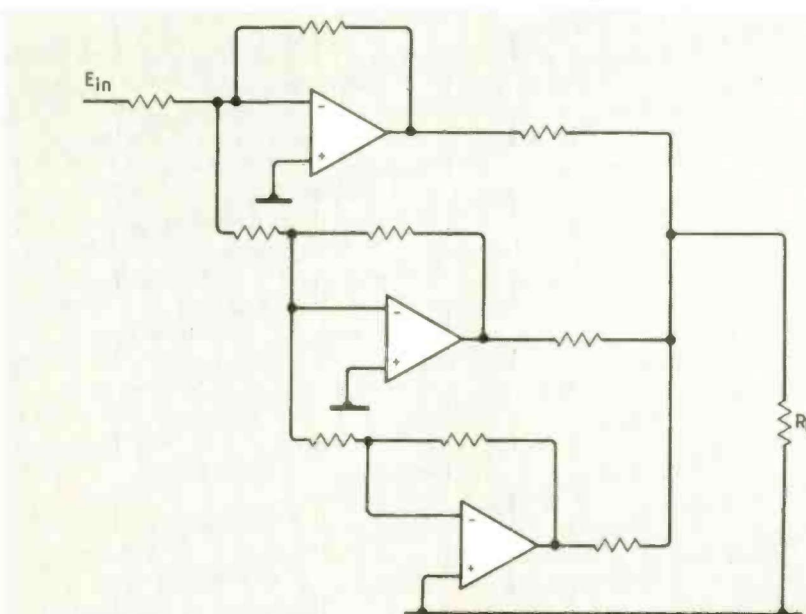


Fig. 3. Iterative feed-forward is theoretically able to reduce distortion as much as required by the use of more feed-forward stages.

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are shown schematically in Figs. 2 and 3. In the case of the iterative feedforward system of Fig. 3, the distortion could in theory be reduced to as low a value as required by the use of extra feedforward stages.

The other approach, applying the error signal to the 'earthy' end of the load, is theoretically capable of completely removing all signal errors, including all forms of noise and waveform distortion introduced by the main amplifier, but will require some set-up adjustment as well as a floating speaker return terminal.

Current dumping. This rather inelegantly named circuit arrangement, introduced by Albinson and Walker⁴ of the Acoustical Manufacturing Company and shown in outline form in Fig. 4, appears superficially similar to Sandman's feed-forward circuit of Fig. 2, except that it requires neither preset adjustments nor a floating 'earthy' load return point, although this similarity was disputed in a subsequent letter from Sandman⁵.

Of all the circuit designs so far offered, this one seemed to come closest to the ideal transistor layout in that the power transistors could operate without any forward bias whatever and yet allow the low-distortion, low-power amplifier to fill in the residual discontinuities.

Certainly this design has excited an enormous amount of interest from other design engineers, if the number of published letters and articles seeking to explain or deny its operation is any indication. For me, the most intellectually satisfying explanation of its method of operation is that due to Baxandall⁶ and is as follows.

Consider a simple amplifier arrangement of the kind shown in Fig. 5(a), consisting of a high-gain linear amplifier A_1 driving an unbiased pair of power transistors Tr_1 and Tr_2 and feeding a load Z_L . Without any feedback, the input/output transfer curve of this circuit would have the shape shown by line (a) in Fig. 6, in which the slope would be steep from M' to N' while Tr_2 was conducting, much flatter between N' and N while only amplifier A_1 was contributing through R_3 to the load current, and then steeper again from N to M , while Tr_1 was conducting.

If overall negative feedback is applied via R_1 , the kink in the transfer curve can be reduced, especially if the gain of A_1 is very high, giving a more linear characteristic of the type shown by line (b) in Fig. 6. However, it would still be unsatisfactory.

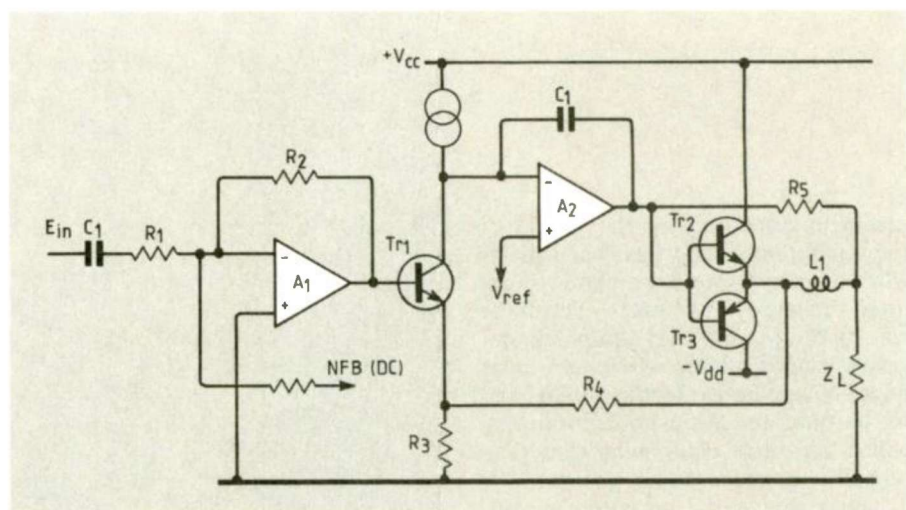


Fig. 4. Acoustical Quad current-dumping amplifier, similar to the Fig. 2 Sandman circuit except that it needs no presets or floating load.

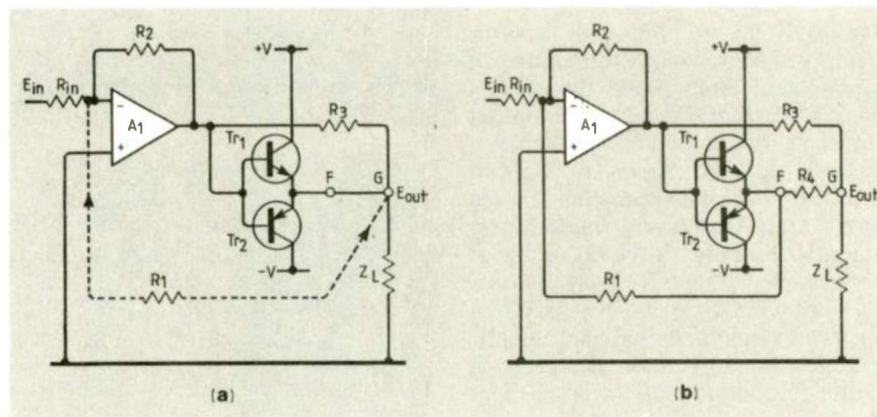


Fig. 5. Operation of the Quad circuit. Basic arrangement of unbiased transistors at (a) is improved by addition of resistor R_4 , which allows almost total elimination of output transistor distortion.

What is required is some method of increasing the amount of feedback while Tr_1 and Tr_2 are conducting to reduce the overall gain so that the slope of the transfer characteristic $\text{M}'\text{-N}'$ and N-M is identical to that $\text{N}'\text{-N}$.

This can be achieved, as shown in **Fig. 5(b)**, by inserting a small resistor R_4 between points F and G in the output feed from $Tr_{1,2}$ and then deriving additional feedback from point F. If the values of $R_{1,2}$ are correctly chosen in relation to the open-loop gain of A_1 , and the output transistors $Tr_{1,2}$ have identical characteristics, the distortion due to the unbiased output transistors vanishes.

Unfortunately, resistor R_4 would be wasteful of power, so Walker and Albinson replace it with a small inductor and substitute a small capacitor for R_3 to compensate for the frequency-

dependent impedance of the inductor.

While this substitution delivers a performance within the range expected from the component tolerances, it complicates the theoretical analysis of the circuit and has led to a lot of subsequent debate, in which the most detailed examination is that due to McLoughlin⁷. He makes a number of valid objections: that it is unlikely that the circuit will completely remove distortion, since no feedback amplifier can ever do this; that the distortion 'cancellation' depends heavily on the precision of the components in the 'bridge' network; and that it presumes that the output slope from M' to N' in Fig. 6 will be identical to that from N to M.

Nevertheless, the circuit works and gives a performance comparable to that obtainable by more conventional means, but without the need to set the

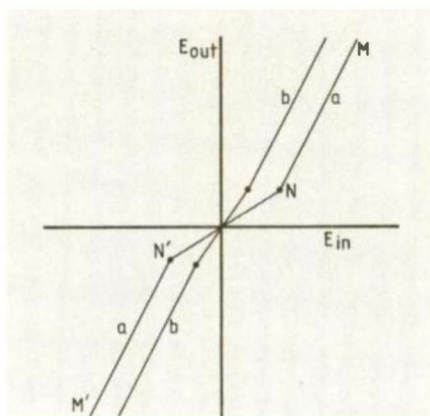


Fig. 6. Transfer characteristic of Fig. 5(a) circuit, with (b) and without (a) feedback.

output transistor quiescent currents – which was the initial objective.

Power mosfets. Junction transistors suffer from a number of inherent problems, such as hole storage and proneness to secondary breakdown and thermal runaway, which becomes more conspicuous when they are used as output devices. With a view to avoiding these problems, Sony introduced high-power junction fets, suitable for use as audio amplifier output devices, in the early 1970s and an amplifier using these was marketed.

However, the parallel development of the insulated-gate power mosfet overtook that of the power fet and, by the late 1970s, there was a range of robust devices with greatly superior characteristics to that of the bipolar junction transistor. Not only are they very fast but, if good chip geometry is employed, the relationship between gate voltage and drain current within the conducting region can be very linear indeed, which facilitates low-distortion push-pull operation. Their very high operating speed allows a substantial improvement to be made in the performance of a quite straightforward audio amplifier by the mere substitution of power mosfets for bipolar power devices, as for example in two designs of my own⁶.

With some exceptions, circuit designers have been slow to adopt these devices, in spite of their attractive features.

Sandman's class S system. A very interesting idea, introduced by Sandman⁷ and somewhat confusingly labelled "class S" (this definition had been used before to refer to a valve grid-bias

mode) is shown in schematic form in Fig. 7.

This employs a high-gain error amplifier A_2 to sense the difference between the output of the small-signal driver amplifier A_1 and that from the unbiased output devices $Tr_{1,2}$ to drive these so that A_1 sees a very high impedance load, under which condition its performance approaches the ideal. As in the current-dumping circuit, the input amplifier provides a drive voltage to the load when the power output devices are non-conducting.

This idea has been adopted in several Japanese power amplifiers and a simplified version of the output stage of the Technics SE-A100 power amplifier – which is representative of all their current range – is shown in Fig. 8.

With reference to my earlier comments on the preoccupation of some manufacturers with what appear to be needlessly high specifications, this design is a typical example, in that it offers a very low steady-state THD figure (0.0002% THD at 1kHz), a very large bandwidth (0.8Hz – 150kHz) and a high

power output (240W into a 4Ω load), though with the penalty of a circuit of considerable complexity.

Pseudo class A systems. Various other circuit arrangements have been explored with the aim of avoiding the need for a pre-set, and perhaps critical value of output-stage quiescent current, without the thermal and other penalties incurred by a pure class A output stage, such as sliding bias or other non-cut-off layouts. Various names have been invented for these, such as "class AA" or "super A".

Of these, one of the more superficially appealing is the floating power supply arrangement in Fig. 9. In this layout, the output devices $Tr_{2,3}$ are operated in class A, with a collector current which is high enough to meet all the anticipated output current demands of the design, but with a supply voltage which is low enough that the total output stage thermal dissipation is within acceptable limits.

The output-stage low-voltage power supply is arranged to 'float', with its

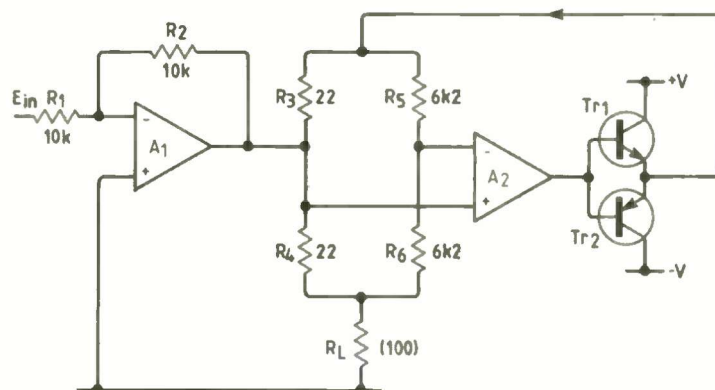


Fig. 7. Sandman's class S amplifier.

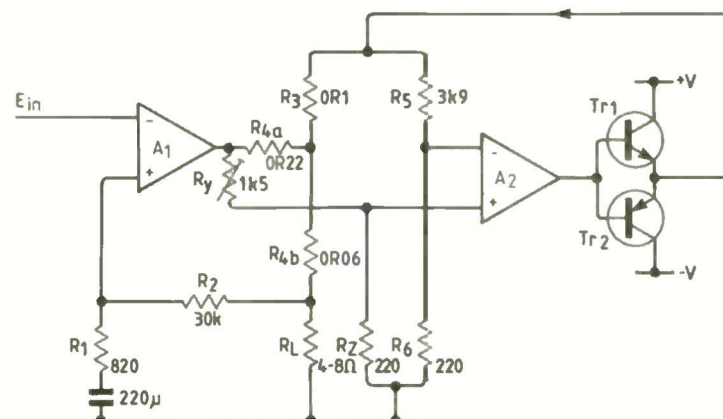


Fig. 8. Technics power amplifier output stage, using the circuit due to Sandman.

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centre tap connected to the output of a high-power, unity-gain, class B power amplifier. There will, of course, be crossover-type discontinuities in the way in which this centre-tap voltage follows the input signal, but this will only appear as a modulation of the supply voltage applied to the output transistors, and it is presumed that the effect on the amplifier output will be negligibly small.

However, there is an inherent problem, which is that the load is connected to the 0V line, but the floating power supply is not. Since this is only returned to this line through the class B amplifier, it follows that this latter amplifier is in series with the load at all times.

The system therefore relies, in practice, on the ability of the negative-feedback loop signal to cause the preceding amplifier stages to supply a correcting signal to the class A output devices to remedy the deficiencies introduced by the class B supply-line driver, and these will only be remediable if the class B power supply driver stage is operated in class AB with some remedial quiescent current, which must be preset.

Also, while this system can give a good steady-state performance, it has problems, as have many other exotic designs, in handling steeply rising signals, which make up so much of programme material.

Fig. 10. Output transistor quiescent-current control in Pioneer M-90 (BK) amplifier.

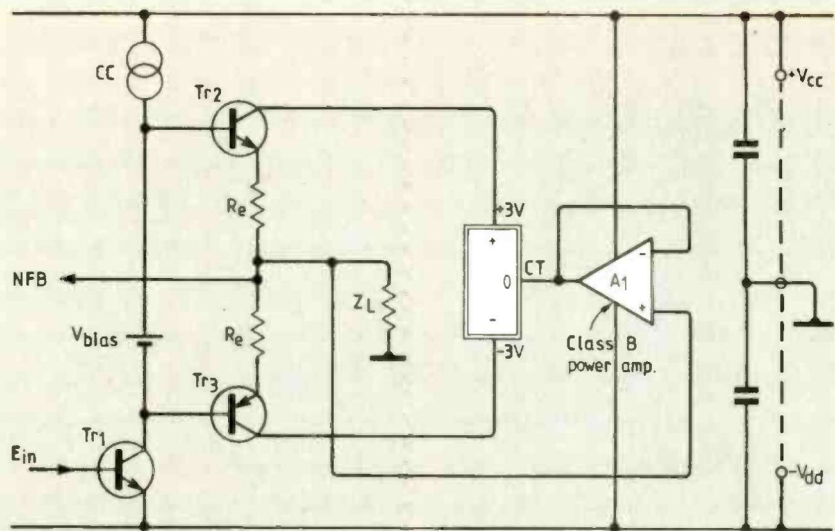


Fig. 9. Floating power-supply pseudo class A system.

Another scheme which aims to provide the advantages of class A operation but with the economy of class AB is the so-called 'non-switching' layout due to Pioneer, used in their M-90 power amplifier, for example.

The layout used is shown in Fig. 10, in which a purpose-designed IC is used to monitor the quiescent current of each group of output transistors and ensure that it remains at the correct level, never approaching cut-off. This also avoids the need for internal pre-set adjustments.

I will examine some of the remaining aspects of this development in the concluding part of this article.

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