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## Letters

# Symmetry in a class B

I read I. M. Shaw's article (June issue, p.265) with great interest, his modification being an alternative to that which 1 briefly described in a recent London lecture to the B.K.S.T.S and which is shown in Fig. 1.

There are many possible variations that be played on the basic quasi-complementary output-stage theme as first conceived by Lin, and in order to be able to assess the relative virtues of these, and perhaps suggest improvements, it is necessary to acquire a detailed and vivid understanding of just whet goes on in these rather subtle circuits. I have found the following approach to be particularly effective.

Referring Fig. 1, the transistor $Tr_1$ is initially regarded as an ideal infinite-output- impedance source feeding its current into $R_1$, which is effectively connected between the points P and Q. It is thus as if a floating signal-voltage source, of internal resistance $R_1$, were connected between P and Q. Now it is of no fundamental importance which point in a circuit is taken as earth, and it is rather convenient, both for promoting an easier understanding and also for performing some initial practical experiments, to earth point Q. Indeed, a few hours spent experimenting with a set-up such as that shown in Fig. 2 will be found very instructive. The effect of finite output impedance in $Tr_1$, (Fig. 1) may be visualized in terms of a resistance shunted across the ideal transistor. This resistance then appears in the position shown in broken line in Fig. 2, and will be seen to apply shunt negative feedback. Since the effective resistance value varies with the instantaneous signal level, the negative feedback introduced is of a nasty non-linear type, and it is better to choose $Tr_1$ for the highest possible output impedance, or even to replace $Tr_1$, by a suitable high-output-impedance transistor pair. The less the local feedback of the above kind, the more will be the overall feedback round the complete amplifier, and this latter type of feedback is the best for reducing distortion. The first requirement, however, is to understand the behaviour of the Fig. 2 circuit without either of these types of feedback.

In reasoning about and experimenting with circuits such as these, I would strongly advocate that voltage-drive should be regarded as the initial ideal concept, the effects of finite input impedance being allowed for later. (For many years I have fe1t that the almost universal tendency to regard transistors as "basically current-operated devices" has exerted a major retarding influence on progress in good transistor circuit design. Mutual conductance should, 1 believe, receive much greater emphasis[1,2,3].)

Fig. 3 shows mutual characteristics, plotted with the aid of a Tekronix curve tracer, for the top (Darlington) pair of Fig. 2 on its own. As the point $B_1$ swings up positive from below cut-off, the driver transistor has developed sufficient mutual conductance, by the time the output transistor comes on, to operate as an emitter follower with approaching unity gain. The initial curvature of the transfer characteristic for the complete pair is thus determined almost entirely by the output transistor and its 0.5-ohm resistor alone. When the output transistor current has risen to about 50mA, the reciprocal of its mutual conductance is about 0.5-ohm and the slope of the pair then reaches about half its final value of 2A/V. Two pairs of this type (requiring complimentary power transistors) would thus have an optimum quiescent current, for minimum crossover distortion, of about 50mA in each power transistor.

Fig. 4 shows characteristics for the lower pair, or "conjugate pair" as it is sometimes called. The sharp turn-on corner, when both diodes are used, arises because the inner transistor of the conjugate pair, as its base swings negative from cut-off, develops considerable voltage gain by the time the necessary half volt or so has been built up across its 100-obm collector resistor to bring the output transistor on. Thus the in initial exponential part of the latter's mutual characteristic, when referred to the input of the pair, is diminished in voltage magnitude by the gain of the first stage, which is in the region of 20. Once the second-stage mutual conductance becomes high enough to establish a sufficient amount of negative feedback via the 0.5-ohm resistor to the first stage emitter, a splendidly linear characteristic, with a slope of very nearly 2A/V is obtained. Unity gain round the loop requires only about 2.5mA in the output transistor, so the overall characteristic looks very linear down to, 10mA. If a push-pull amplifier were made with two such conjugate pairs, the correct quiescent current, giving half the full slope from each pair, would be about 2.5mA in each power transistor.

Between $B_1$ and earth we have (a) the driver emitter-base voltage, (b) the voltage across a 100-ohm resistor shunted by a "diode" (the input of the power transistor) and (c) the voltage across the 0.5-ohm resistor. By adding a 100-ohm resistor shunted by a silicon junction diode in the emitter lead of the conjugate-pair driver transistor, we introduce into the path between $B_2$ and earth a voltage component similar to that existing between base and emitter of the output transistor, and thus make the overall behaviour of the lower pair simulate closely that of the upper pair. An alternative solution, i.e. that due to Mr. Shaw, is to insert a power diode in series with the 0.5-ohm resistor of the lower pair - the resistor value may, with advantage be slightly reduced to allow for the spreading resistance of the diode.

So far we have considered the behaviour of the circuit with low-impedance voltage drive. In practice, however, $R_1$ in Fig. 1 is not usually low enough, in relation to the driver-stage input impedance, to justify this assumption fully; though the high-current-gain transistors now becoming common make the approximation to voltage drive tend to be better than in the pest. To allow for the effect of a finite source resistance, we need to know how the driver base current varies with the base voltage in Fig. 2. In the top pair, before the output transistor comes on, the driver transistor has 100-0hms in its emitter and therefore has a high input impedance (not less than 20 kohms if $\beta = 200$). In the lower pair, when no diode is used, the driver transistor, before the output transistor comes on, has only 0.5-ohm in its emitter, which is negligible. Consequently, as its base swings negative, the input current rises in a rapidly increasing exponential manner until the output transistor comes on and feedback to the driver emitter is established, after which it rises much more gradually. With the diode and resistor inserted in the driver emitter lead, however, the input current is caused to vary in substantially the same manner as in the Darlington pair. These effects are illustrated by the measured input-current characteristics of Fig. 5, from which it will be seen that a diode and resistor in the driver emitter lead give an input-current characteristic much more like that of the Darlington pair than does a diode in series with the output transistor.

In Fig. 6 are shown transfer characteristics for the complete push-pull circuit of Fig. 2, under a variety of conditions.

In conclusion, I would like to express my opinion that even without these recent diode refinements - or earlier rather less satisfactory distortion-reducing dodges - the better versions of 6-transistor quasi-complementary class B amplifiers already have a distortion level which is subjectively quite negligible, but the use of diodes should enable similar results to be obtained with a smaller input signal level, less feedback then being required. It is perhaps worth mentioning that I have seen commercial versions of this type of circuit with overall voltage gains varying from 4 to 200.

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## References


**(1)** "Transistor Mutual Conductance", Editorial in *Electronic Technology*, Vol. 38, No. 3 (March 1961).

**(2)** "Low Distortion Amplifiers", P. J. Baxandall*, J. Brit. Sound Recording Assn.,* Vol. 6, No. 11, pp.246-256. (Nov. 1961).

**(3)** "The Bipolar Transistor as a Voltage-operated Device", E. A. Faulkner, *J.I.E.R.E.* (Brit.), Vol. 37, No. 5, pp. 303-305 (May 1969).


## List of Figures

**Fig. 1.** - An effective modification for reducing crossover distortion.

**Fig. 2**. - Experimental circuit with shifted earth point. The broken-line resistor represents the effect of finite output resistance in $Tr_1$ of Fig. 1. The 220-ohm base resistors are to prevent parasitics; the writer's rather straggly version also required a series combination of 33 ohms and 100pF between abase and collector of the top driver transistor only.

**Fig. 3.** – Characteristics for upper (Darlington) pair of Fig. 2. Curve (a) circuit as shown; (b) $R_2$ short-circuited and (c) $R_1$ omitted, $R_3$ short-circuited.

**Fig. 4.** - Characteristics for lower (conjugate) pair of Fig. 2. Curve (a) circuit as shown; (b) diode removed; (c) S closed, power diode inserted in series with $R_3$ (Mr. Shaw's scheme); (d) S closed, otherwise as shown; (e) S closed, no diode, $R_3$ short-circuited; and (f) as for (e) but with $R_3$ removed.

**Fig. 5(a)**. – Input characteristic for upper (Darlington) pair of Fig. 2.

**Fig. 5(b).** – Input characteristics for lower (conjugate) pair of Fig. 2. Curve 1, S closed, power diode in series with $R_3$ (Mr. Shaw's scheme).

**Fig. 6.** - Plots of $I_L$ (vertically, 100mA/large division) against $V_S$ (horizontally, 0.1V/large division). The steeper curve in each case is for $R_S = 0$, and the less steep curve is for $R_S = 5$ kohm. Zero $I_L$ and $V_S$ at centre of plots. Quiescent current approx. 60 mA in all cases. (a) Fig. 2 circuit with S closed; (b) As for (a) plus $R_3$ short-circuited (Mr. Shaw's Fig. 1); (c) S closed, power diode in series with $R_3$ which was reduced to about 0.35-ohm to compensate for diode spreading resistance (Mr. Shaw's Fig. 2 scheme); and (d) Circuit as shown in Fig. 2, with slight extra improvement due to inserting 10 ohms in series with top driver emitter to compensate for diode spreading resistance.

Figure 1

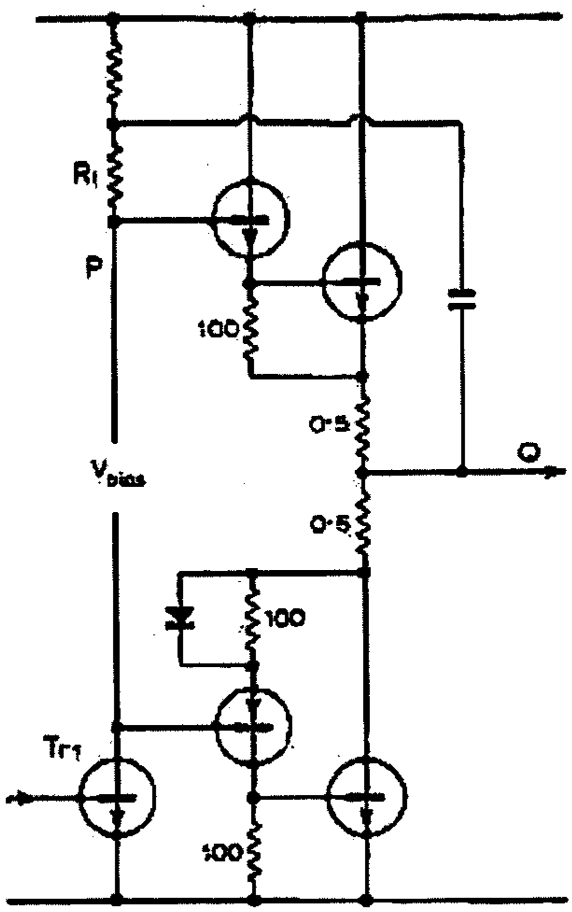


Figure 2

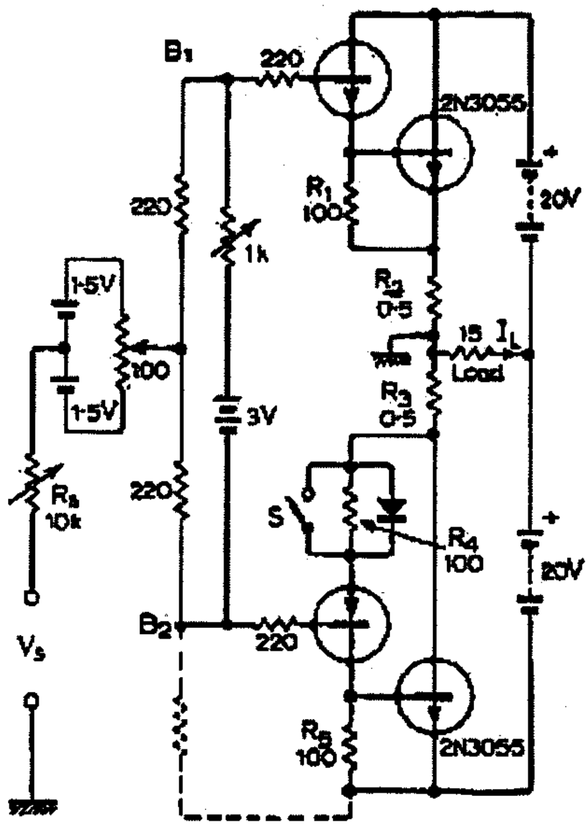

Figure 3

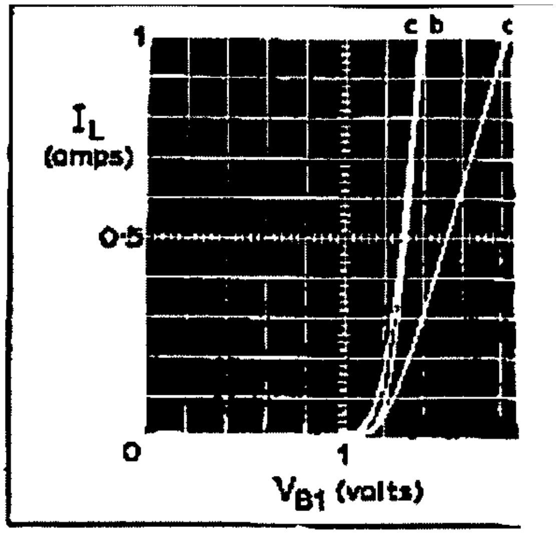


Figure 4

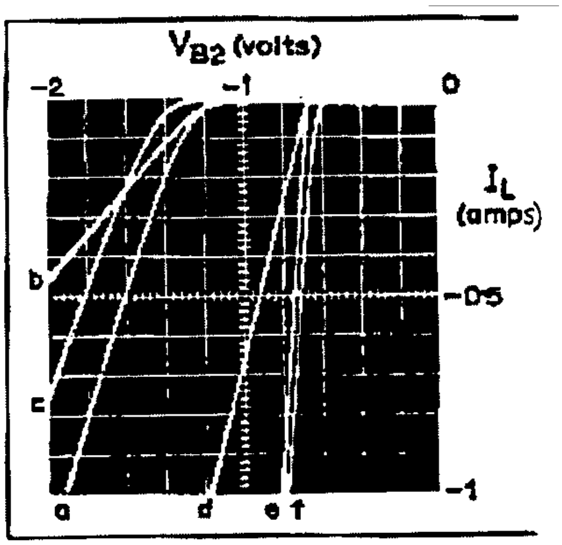

Figure 5(a)

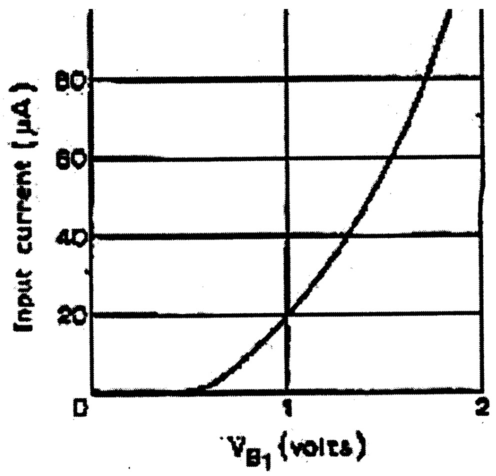


Figure 5(b)

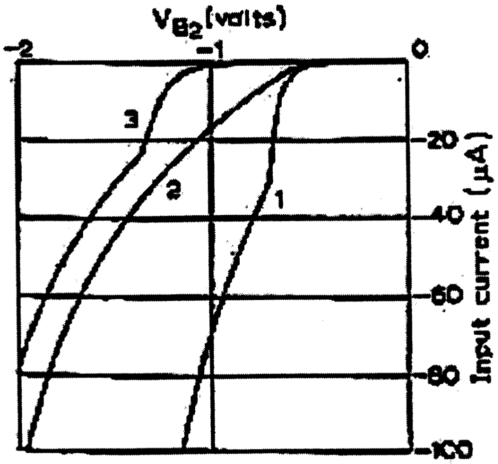

**Figure 6**