

Fig. 6. Use of junction fet as 'tail' load in long-tailed pair.

above, which could reasonably be expected to offer an improved slewing characteristic in comparison with the more conventional asymmetrical layouts of existing op-amp circuitry lie in improved rejection of supply-line signal breakthrough, improved open-loop linearity, and improved common-mode rejection, in respect of a signal applied equally to the inverting and non-inverting signal inputs.

Consideration of these aspects led to the thought that junction fets, with their very flat V_{gs}/I_d characteristics, shown typically in Fig. 5, would offer both improved supply-line signal rejection, when used, for example, as a 'tail' of a long-tailed pair, as in Fig. 6, but would also make very good amplifying devices, for

the same reason, with good rejection of drain-potential signal breakthrough, and good common-mode rejection.

A further thought was that, since a junction fet will normally require a gate potential which is negatively offset in relation to that of its source, it would be possible to combine a pair of fet long-tailed pairs so that each acted as the 'tail' of the other, as shown in Fig. 7. An attractive feature of this arrangement is that the 'tail' in such circuit provides an entry route for unwanted signal components into the input of the amplifier. If this can be removed, this would lessen such unwanted breakthrough.

The practical embodiment of this design is shown in Fig. 8. In this a pair of junction transistor 'current mirrors' (Tr_5 , Tr_6 , Tr_7 and Tr_8) in the drain circuits of the fets combine the output currents, and generate a drive signal for the output transistor pairs.

These are connected in 'cascode' form, in the interests of high output impedance (desirable to minimize supply-line signal breakthrough) and good linearity.

The output resistor chain, (R_{10} , R_{12} and R_{13}) provides the necessary forward bias for the cascode 'followers', and the resistors R_8 and R_9 cause the output current to be routed through the sensor half of the 'current mirror' to provide a measure of d.c. negative feedback to stabilize the cur-

rent flow through Tr_9 and Tr_{12} .

Several units of this design have been made, and the performance, which has proved consistent from one unit to the other, is typically as shown, when operated from a $\pm 24V$ supply.

Gain 30,000 at 330Hz, open-loop.

Bandwidth. d.c. — 100kHz (—3dB), at gain $\times 50$.

Harmonic distortion, Open loop. Below background noise level.

Harmonic distortion, Gain $\times 50$ Less than 0.002% at 10V r.m.s. output, at 1kHz and 20kHz.

Output voltage swing. 15.5V r.m.s.

D.c. offset. +50mV without adjustment. Trimmable to $\pm 3mV$.

Square-wave overshoot. Nil.

Current consumption. 8mA.

Minimum supply-line voltage $\pm 12V$.

For optimum performance from any such units, it is recommended that the d.c. supply lines should be decoupled to the 0V line at points close to the supply input terminals on the board, using good quality non-polar dielectric capacitors, of 0.1-0.47 μF , and that the supply lines themselves should be derived from low a.c. impedance, low-noise sources.

A number of these modules has been built, and experimentally substituted for existing op-amps in audio circuits — a quite straightforward exchange when $\pm 15V$ lines are available — and I am very pleased with the resultant sound quality. I don't want to make specific claims, since I realise the psychological difficulties in this type of evaluation, unless a statistically adequate number of listeners is available, and the tests are conducted in a manner which avoids the possibility of prejudice in the resultant assessments.

On the general subject of the desirability of symmetrical circuitry for audio use. I feel that if it can be employed without incurring other significant penalties, such as a worsening of quiescent current stability, or a degradation of reactive load step function response it is a generally desirable move.

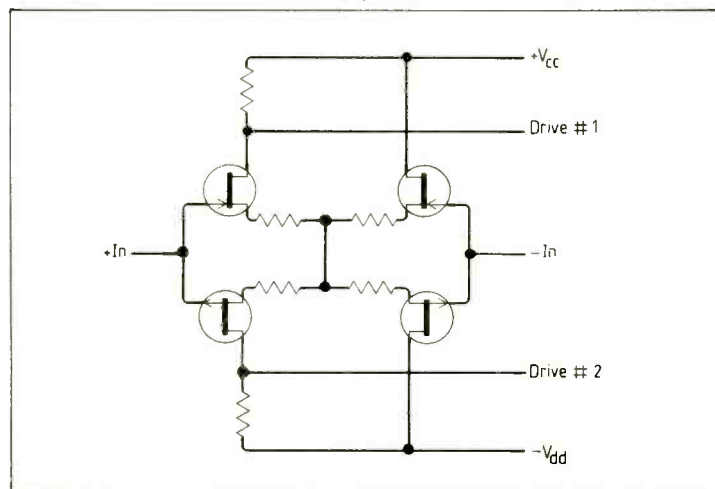


Fig. 7. Symmetrical fet input stage.

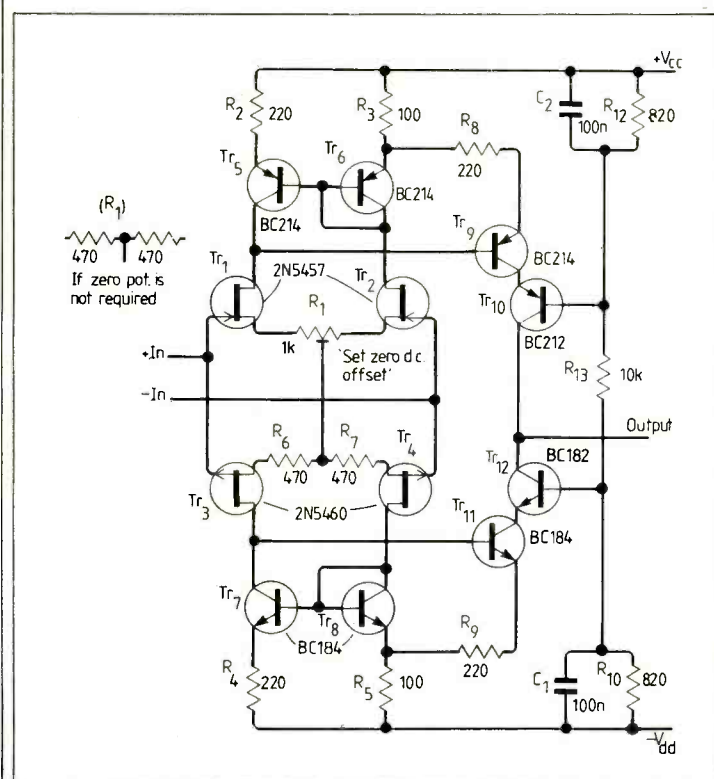


Fig. 8. Symmetrical, low-distortion gain block.

Layouts for the two printed-circuit boards can be obtained from this office. Please enclose a stamped, addressed envelope and mark your letter 'symmetrical amps'.