here the better if good bass response is to be secured.

Figure **2b)** shows a corresponding equivalent circuit of the transformer at high frequencies. At these frequencies primary inductance has no influence but leakage inductance in conjunction with the winding capacitance forms a second-order low-pass filter.

Both leakage inductance and winding capacitance are functions of the way the transformer is built. Reducing these factors is usually done by sectioning the transformer windings. Again you can see from the equivalent circuit that leakage inductance needs to be minimised for good ht response.

When calculating values of these inductances for a given anode resistance, calculations show how rapidly required inductance falls when anode resistance is lowered. In fact, if output impedance could be made zero the required primary inductance would also disappear. Similarly, it can be shown that transformer distortion is also highly dependent on anode resistance and similarly drops to zero with zero impedance drive.

One argument which can be put forward in defence of triode output stages is that they have lower anode impedance than pentodes. Hence, primary inductance can be made lower for a given bass extension. Most practical designs use overall negative feedback to lower effective anode resistance.

Normally the loop is taken from the output winding of the transformer – including it within the feedback loop. However, due to reactive elements present in an output transformer the amount of feedback that can be employed in this manner is strictly limited.

One of the best ways of solving the problem is to use a cathode follower, **Fig. 3.** It is analogous to the more familiar emitter follower with similar features. Voltage gain is always less than unity and output impedance is significantly lower than that obtained from a triode used in a normal grounded cathode stage. Distortion is typically an order of magnitude smaller.

These limitations make the circuit more of a laboratory curiosity, since driving it fully would require almost twice the signal swing allowed by the ht voltage. However, the circuit is tantalising and I played with the idea of a push-pull cathode follower output driven by an inter-stage transformer before developing the present circuit.

There is however another way of producing a cathode follower style output stage which possesses all the virtues and few of the vices of a conventional valve output stage. The circuit is an amalgam of a transconductance and a transresistance amplifier, **Fig. 4**.

I cannot understand why this particular circuit is not used more often since it allows very high performance with a low component count. Figure **4a** shows a transimpedance amplifier operating as a conventional virtual earth amplifier.

If open-loop gain is very high then closed-loop performance is determined by the ratio of R_1 to R_2. If R_1 were to be substituted for a constant current source, Fig. **4b)**, the amplifier would 'see' 100% negative feedback at its inverting input and voltage gain would be zero.

Replace the current source with a transconductance amplifier and the amplifier will give an output of IR_1. Distortion generated by the transimpedance stage will be very small because feedback factor B (the proportion of

Supplying ht

Power supply for the circuit is conventional. Ht is derived from the 280V secondary coil of T_2 – full-wave rectified by BR_1 and smoothed by the parallel combination of C_5 and C_6. Apart from extra ripple rejection this combination of capacitors stores a huge amount of energy – around 68J. This helps maintain supply lines even when feeding awkward loads.

Supply lines for the op-amp circuit are derived from the heater secondaries. For a stereo amplifier, 6V at 3A minimum/channel is required. A 6-0-6V, 50VA transformer is suitable.

Secondaries connect in series and the voltage doubler D_1 and D_2 provides the dual dc supply, smoothed by C_7 and C_8. Heaters connect in series/parallel across the 12V supply as shown in the schematic overleaf.

Because of the totally balanced operating mode of the amplifier, ripple voltages effectively cancel out – simplifying psu design.

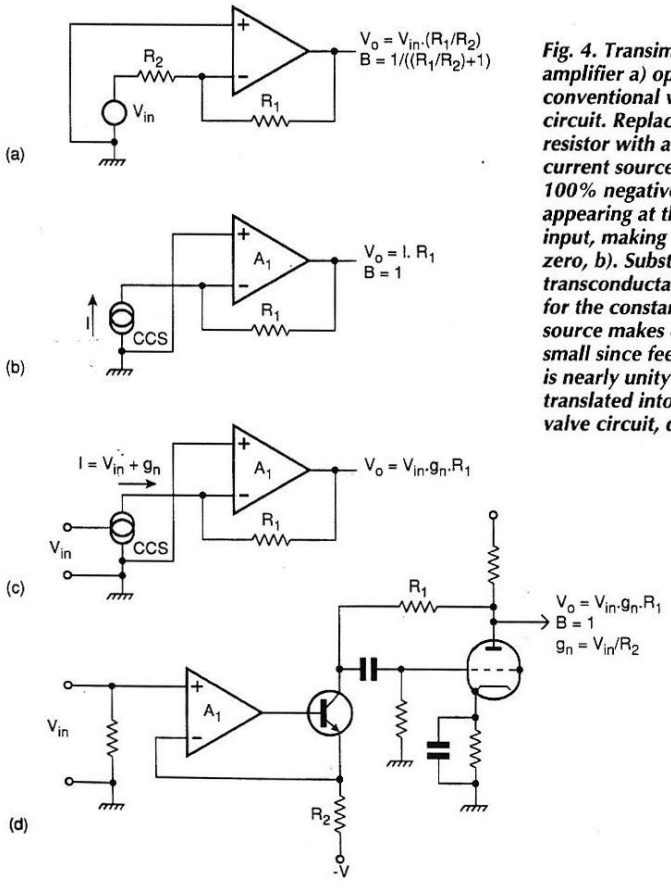

Fig. 4. Transimpedance amplifier a) operating as a conventional virtual-earth circuit. Replacing the resistor with a constant-current source results in 100% negative feedback appearing at the inverting input, making voltage gain zero, b). Substituting a transconductance amplifier for the constant-current source makes distortion very small since feedback factor B is nearly unity c). Circuit c) translated into a hybrid valve circuit, d).