CURRENT-DUMPING AUDIO AMPLIFIER

The "distortionless" character of the current dumping (c-d) audio amplifier is said to be dependent on a bridge balance. Presumably, this balance is like any other circuit condition in that it can only be set up with a tolerance which can be made smaller as the cost of the arrangement increases.

It therefore seems unrealistic to compare a theoretical balanced bridge with a practical conventional feedback arrangement (as some of your correspondents have done), to evaluate the distortion performance of the c-d circuit. A fairer approach would be to ask how badly the distortion performance of a practical c-d circuit, using reasonable techniques, would be affected by unbalances to be realistically expected, and how it would compare with the performance of a comparable conventional arrangement.

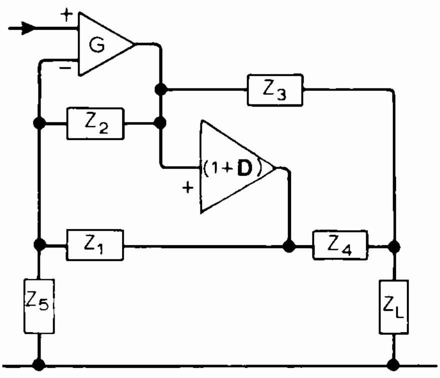
The two arrangements are directly comparable in principle. If for comparison we use a negative feed back arrangement around a distorting amplifier of gain $G(1+\mathbf{D})$ where G is a linear gain factor and $\mathbf{D}$ a distortion operator, we can take the closed-loop gain expression.

$$\frac{G(1-\mathbf{D})}{1+FG(1+\mathbf{D})}$$

$$=\frac{G}{1+FG}\cdot(1+\gamma\mathbf{D}-\gamma n\mathbf{D}^2+\gamma n^2\mathbf{D}^3\ldots)$$

where F is the feedback fraction,

$n=\dfrac{FG}{(1+FG)}$ and $\gamma=\dfrac{1}{(1+FG)}$, and derive an expression of analogous form for the following c-d circuit configuration:



in which the class A amplifier is assumed linear with gain G, the current-dumpers unity gain with distortion $(1+\mathbf{D})$, and both amplifiers assumed to have zero output impedance.

The closed-loop gain is

$$\frac{L(1+\beta\mathbf{D})}{K^*(1+\alpha^*\mathbf{D})}$$

$$=\frac{L}{K^*}[1+(\beta-\alpha^*)\mathbf{D}-(\beta-\alpha^*)\times$$

$$[\alpha^*\mathbf{D}^2+(\beta-\alpha^*)\alpha^{2}\mathbf{D}^3\ldots],$$

where $L=\dfrac{Z_L(Z_3+Z_4)}{Z_3Z_4+Z_4Z_LZ_3}$, $\beta=\dfrac{Z_3}{Z_1+Z_2}$,

$\dfrac{1}{K^*}=\dfrac{G}{1+GK}$, $\alpha^*=\dfrac{\alpha GK}{1+GK}$, $\alpha=\dfrac{Z_2}{Z_1+Z_2}$

and $K=\dfrac{Z_5(Z_1+Z_2)}{Z_1Z_2+Z_2Z_5+Z_5Z}$.

The closed-loop gain expression is of similar form for both configurations, except that the distortion coefficient γ for the conventional arrangement is replaced by the difference $(\beta-\alpha^*)$ in the case of c-d.

It is apparent that the c-d as well as the conventional configuration produces high-order distortion as a result of applying feedback. But whereas with the conventional arrangement the distortion coefficient γ can only be minimised by raising G, the right-hand half of the bridge in the c-d configuration (theoretically) allows complete cancellation of the distortion by making $\beta=\alpha^*$ exactly. This balance equation expands to

$$\frac{1}{1+GK}+\frac{Z_1}{Z_2}=\frac{Z_4}{Z_3}\left(1-\frac{1}{1+GK}\right)$$

and reduces to the familiar $Z_1Z_3=Z_2Z_4$ as $G\rightarrow\infty$.

We can get a rough comparison between the performance of a slightly unbalanced c-d bridge and a conventional arrangement if we look at Mr P. J. Walker's article (Dec. 1975, p.562) and see that in the Quad 405 circuit the real parts of $Z_1/Z_2+1/(1+GK)$ and Z_4/Z_3 are of the order of 0.01. Assuming the bridge initially balanced, a perturbation of 5% in any of Z_1 to Z_5 or G leads to a residual $(\beta-\alpha^*)$ of the order of 0.0005. Other things being equal, this indicates the same distortion performance as a conventional arrangement in which G is 10,000 and $FG = 2000$, i.e. $\gamma = 0.0005$. The difference is that the c-d configuration does not call for any particular value of amplifier gain or loop gain to reach this performance, provided the balance conditions are adjusted to take the finite G value into account. The Quad design appears to use values of the order of 1000 and 200. At the assumed 5% tolerance, therefore, the c-d configuration allows economy of amplifier gain and loop gain for the given distortion performance. This should evidently recommend itself as a worthwhile advantage, accompanied by fewer feedback loop stability problems.

However, other things may not be equal. The unbiased current-dumpers may generate more distortion than a conventional class-B transistor pair, thus calling for more accurate cancellation. 5% may not be an easily achievable tolerance for the bridge balance, particularly where Z_2 and Z_4 are reactive. It can be seen from the expanded balance equation that a finite G represents (from the point of view of bridge balance) a load resistance in parallel with Z_2, so that even where Z_2 is purely capacitative,, a resistor is needed in series with the opposite complementary arm L_4. This balancing resistor is only a fraction of an ohm, so that its 5% tolerance will be in the order of milliohms, possibly comparable with wiring and joint resistances. Of course the accuracy of bridge balance also depends on the value of the amplifier gain G, not the best of well-defined or drift-free parameters in practice.

Furthermore, when reactive bridge arms are used, as seems essential in practice, unbalanced imaginary components of $(B - \alpha^*)$ may be present and do more harm than would appear likely from the high cut-off frequencies which the reactances introduce. As pointed out by Mr P. J. Baxandall (July 1976, pp 60-1), the amplification of a mid-frequency sinusoidal signal by the c-d arrangement requires handling of a non-sinusoidal and hence wide-band signal within the feedback loop. Thus reactance balance may turn out more critical than otherwise expected, and difficult to achieve where there is phase shift at high frequencies in the class A amplifier and hence an imaginary component of G to complicate the balance equation. Again, the output impedance of the dampers is unlikely to be negligible in relation to Z_4.

It would be of interest to have some practical figures for the importance (or otherwise) of these expected sources of disturbance in the Quad commercial realization of this elegant new design. It is no doubt a worthwhile advance, but "distortionless"? The c-d circuit does away with the unattainable criterion of infinite loop gain for distortionless output, as with the conventional negative feedback arrangement, but replaces it with the equally unattainable criterion of perfect accuracy of bridge balance. The results of practical deviations from the theoretical requirements in the two cases are qualitatively the same

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Mr Walker replies.

No indeed we don't claim to make distortionless amplifiers. The term – in so far as it has been used – is intended to indicate that there is a 'theoretically accessible' state where the output stage distortion will cancel to zero, without calling upon infinite loop gain. Compared with straight overall feedback, the barriers preventing us reaching perfection are of a fundamentally different kind and, as Mr Stancliffe rightly points out, we want to know whether this change in kind can be applied to advantage in a practical amplifier. We have chosen to apply the technique to amplifiers with zero bias output stage because if we can overcome the fundamental problems of these amplifiers and raise their performance to impeccable standards then they emerge as essentially "right" and all the rigmarole of biasing becomes a thing of the past.

In a zero bias amplifier there is a no-man's land or backlash region between one output transistor turning off and the other turning on. It is to be hoped that the driver transistor transverses this gap as quickly as possible and to help it out it is usual to find a resistor bypassing the output stage so that there is some current to the load during this transition period. All such amplifiers suffer from the fact that the forward conductance during the transisition is less than the forward conductance when one or other of the output transistors is operational, so that the whole transfer characteristic has a portion in the middle with a different slope to the remainder. In order to produce an acceptable standard of performance the bypass resistor is made as low as possible consistent with the driver's ability to supply the extra current required and heavy overall feedback is applied. Both of these manoeuvres reduce the change of slope in the transfer characteristic. There are several well respected and excellent commercial amplifiers of this type available, particularly in the high or "super power" class.

Current dumping is really a simple means of adapting such an amplifier whereby the two slopes are separately defined and can be made equal by the suitable choice of a few passive components. With Mr Stancliffe's criterion of a total error of 5% in these components the change of slope will be reduced 20 times without calling on any increase of feedback. Evidently the distortion will fall by a similar amount!

In practical amplifiers aimed at very low distortion there can be – and usually are – other factors which may determine a lower limit to the distortion. In all class B amplifiers, for example, parts of the circuit and power supply carry heavy current highly distorted signals (half sinewave for a single tone signal). The minutest coupling between these and other parts of the circuit which should be pure quickly builds in distortion which no amount of d.c. balancing will remove. Zero bias and c.-d amplifiers require parts of the circuit to have wide bandwidth and very fast slew rates which may not be fully achieved. Output transistors do not turn on or off as simply as one would wish.

These factors are really a matter of detail design and therefore difficut to quantify. Nevertheless, the 26dB (20 times) improvement is there for the taking and nearly for free. With care, most of it can be realised in a practical amplifier.