4597 (N-2)

Novel Feedback Topology Obviates the Need for High Loop Gain

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Presented at the 103rd Convention 1997 September 26–29 New York

AES

AN AUDIO ENGINEERING SOCIETY PREPRINT

Novel feedback topology obviates the need for high loop gain

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Abstract

A novel feedback topology is presented, differing from 'classical' feedback by an additional feedback term, inversely proportional to the open-loop transfer function. The result is the elimination of the open-loop transfer function from the closed-loop equation, without requiring high loop gain. An example circuit, implemented with simple means, is discussed, showing a distortion reduction of several orders of magnitude.

0. Introduction.

Classical negative feedback in an amplifier goes back to Black [1], [2]. It is a widely used technique to reduce amplifier shortcomings like distortion and noise in the system output signal. Briefly, for a circuit with an open-loop transfer function A and feedback factor ß (see Fig. 1a), the closed loop transfer function is described by the well-known expression

$$\frac{Vo}{Vi} = \frac{A}{1+A.\beta} \qquad (1)$$

where the term A.ß represents the loop gain. When the loop gain is made high enough, the closed-loop system transfer function approaches 1/ ß. As a result, the influence of the open-loop transfer function A on the closed-loop transfer function becomes vanishingly small. However, Bode [3] showed that the loop gain cannot be made arbitrarily high; it must be limited if the system is to remain stable, thus limiting the beneficial effects of negative feedback that can be realized. There are other drawbacks to high loop gain, like the increased susceptibility to internal overdrive under transient conditions, to name just one. It is therefor logical that various schemes have been developed to obtain low distortion with limited loop gain (for example feed-forward), or to circumvent Bode's limit on loop gain (for example nested differential feedback). However, these approaches significantly increase system complexity and cost, with limited benefits.

1. New approach.

Traditionally, designers strive to maximize loop gain while maintaining stability so that the significance of the term '1' in the denominator of equation (1) is reduced and can be ignored. The present approach however aims at eliminating this term from the expression of the closed-loop transfer function altogether, irrespective of the loop gain. This can be done by replacing the generic term 'ß ' in equation (1) by 'ß-1/A ', which would eliminate the term 'A' from the closed-loop transfer function. The conceptual approach is shown in Figure 1b. There are two feedback paths: the path via Vf of a fraction ß of Vo to the inverting input of the summing network (the 'classical' path), and an additional, positive, feedback via Vc to the non-inverting input of the summing network, of a fraction 1/A of Vo. By treating the two feedback-paths separately, as described by Graeme [4], the compound *negative* feedback-factor F becomes:

$$F = \beta - \frac{1}{A}$$

Substituting this for ß in equation (1) yields the closed-loop transfer function:

$$\frac{1}{\beta}$$

which is what we were after.

It is interesting to note that a signal that represents the fraction of Vo by the inverse of the open-loop transfer function can be picked off at the amplifier input voltage Va, and this realization leads to Figure 1c. Va is fed back through scaling network D as Vc to the non-inverting input, while Vi, Vc and Vf are scaled by summing network C. The compound *negative* feedback factor to the input of amplifier A in Fig. 1c thus becomes:

$$F = C.\beta - \frac{C.D}{A}$$

By inspection we see that $Va = C.(Vi - Vf + Vc)$. Because $Vc = D.Va$, $Vf = \beta.Vo$ and $Vo = A.Va$, we find that:

$$Vo = A.C.Vi - A.C.\beta.Vo + A.C.D.\frac{Vo}{A}$$

which leads to:

$$\frac{Vo}{Vi} = \frac{A.C}{1 + A.C.\beta - C.D}$$

Now if we choose the scaling coefficients D and C such that $C.D = 1$, the closed loop gain again reduces to:

$$\frac{Vo}{Vi} = \frac{1}{\beta}$$

which is the result sought. We have eliminated the open-loop transfer function from the expression for the closed-loop transfer function, independent of the open-loop transfer function A. The fraction of the output voltage that is fed back to the amplifier input in addition to the 'classical' term ß is:

$$\frac{C.D}{A}$$

which is inversely proportional to the open-loop transfer function A.
The concept of Fig. 1c can for example be realized as shown in Fig. 1d. Summing network C in Fig. 1c is replaced by a gain block with gain G. Summing network D is replaced by a positive feedback path via Z1 and Z2. We will assume that the in- and output impedances of G and A can be neglected, which does not affect the principle of the new topology. By inspection of Fig. 1d we find that:

$$V- = \beta.Vo \quad \text{and} \quad V+ = Vi + (Va - Vi).\frac{Z2}{Z1+Z2}$$

Since $Vo = G.A.(V+ - V-)$ and $Va = \frac{Vo}{A}$, we conclude that

$$\frac{Vo}{Vi} = \frac{G.\frac{Z1}{Z1+Z2}}{\frac{1}{A}.(1 - G.\frac{Z2}{Z1+Z2}) + \beta.G}$$

If we dimension Z1 and Z2 such that the positive feedback factor $\frac{Z2}{Z1+Z2}$ is the reciprocal of G, we get:

$$\frac{Vo}{Vi} = \frac{1}{\beta}.\frac{Z1}{Z1+Z2} \quad \text{--(2)}$$

which again is independent of the open-loop transfer function A.

2. A practical implementation.

Figure 2 shows a practical implementation of the new topology. Gain-block G is based on a PA630 current-conveyor cell with on-chip buffers. For clarity, the biasing for the PA630 and for the amplifier circuit are not shown in detail. The positive feedback via Ra and Rb is approximately:

$$\frac{1}{4.9}$$

Therefor, the gain of the gain block is adjusted with Rg to be 4.9, the reciprocal of this. In this circuit, resistor Rb is the only difference with a 'classical' feedback circuit. By removing or including Rb, comparisons between 'classical' feedback and the new topology can easily be made. It should be noted that, according to equation (2), the absolute value of the closed-loop gain, in case Rb is inserted, decreases by a factor:

$$\frac{Z1}{Z1+Z2}=\frac{Rb}{Ra+Rb}=0.8$$

from the value expected by using the negative feedback path only. Comparative measurements are shown in Figures 3 to 6. In Fig. 3, the THD+N with the new topology (the dotted curve) drops down to the level of the residual THD+N of the PA630 current conveyor. A similar reduction can be seen in Fig. 4, which shows a large reduction in harmonic components with the new topology (Fig 4b) versus the 'classical' case without Rb (Fig. 4a). Finally, Fig. 5 shows the effectiveness of the new topology (dotted curve) to reduce THD+N with increasing output versus the 'classical' circuit (solid curve). Clearly, the new topology is very effective at reducing amplifier distortion, however one looks at it.

3. Conclusion.

A novel feedback topology has been developed that eliminates the open-loop transfer function from the expression of the closed-loop transfer function of a feedback system without requiring high loop gain. An example circuit was presented, showing that the new topology can be implementation with simple means. Measurements on the example circuit show that the new topology reduces amplifier distortion by several orders of magnitude. The new topology can be applied to any system that uses feedback to linearise the transfer function, be it an electronic, mechanical, pneumatic, hydraulic, optical or hybrid system. It allows the design of lower cost, simplified systems with the high degree of stability resulting from low loop gain, together with the accuracy and predictability which is the hallmark of high feedback-factor systems.

The new topology described in this paper is the subject of a pending patent. Licensing inquiries should be directed at the author.

References

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[3] Bode, H. W. "Network Analysis and Feedback Amplifier Design", Van Nostrand, Princeton, N. J. 1945.

[4] Graeme, Jerald. "Generalized op-amp model simplifies analysis of complex feedback schemes", EDN, April 15, 1993.

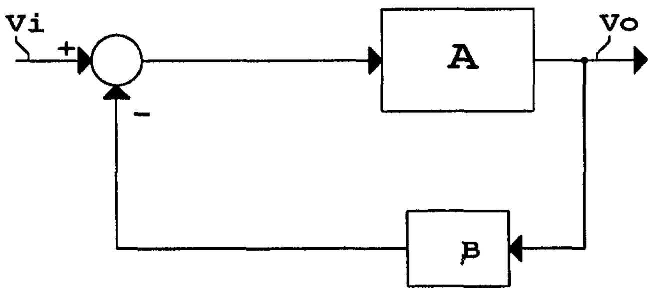

Figure 1a

'Classical' feedback topology

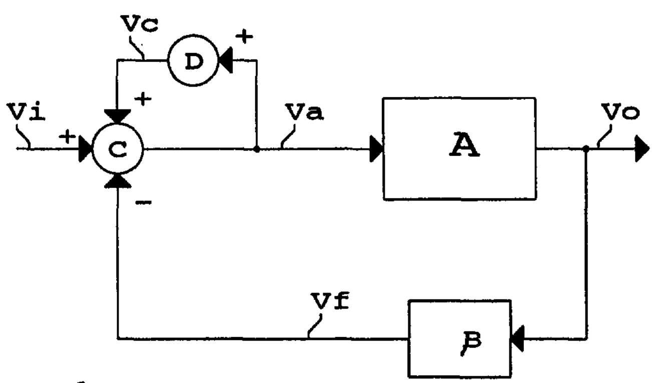

Figure 1c

Using the input to 'A' as the
'inversely proportional to A' fraction of Vo

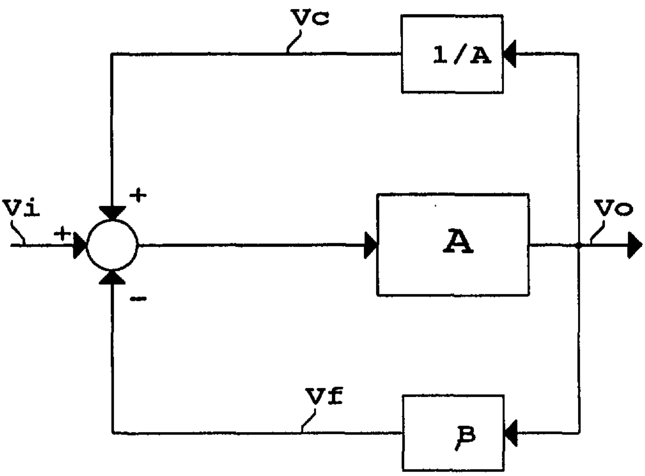

Figure 1b

Conceptual new topology

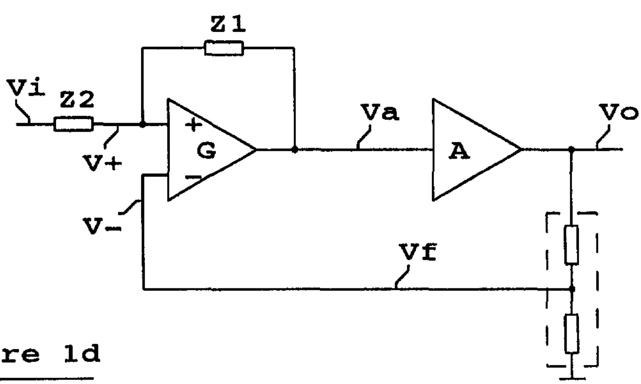

Figure 1d

Realisation with gain block G and Z1, Z2, replacing C and D in Fig. 1c.

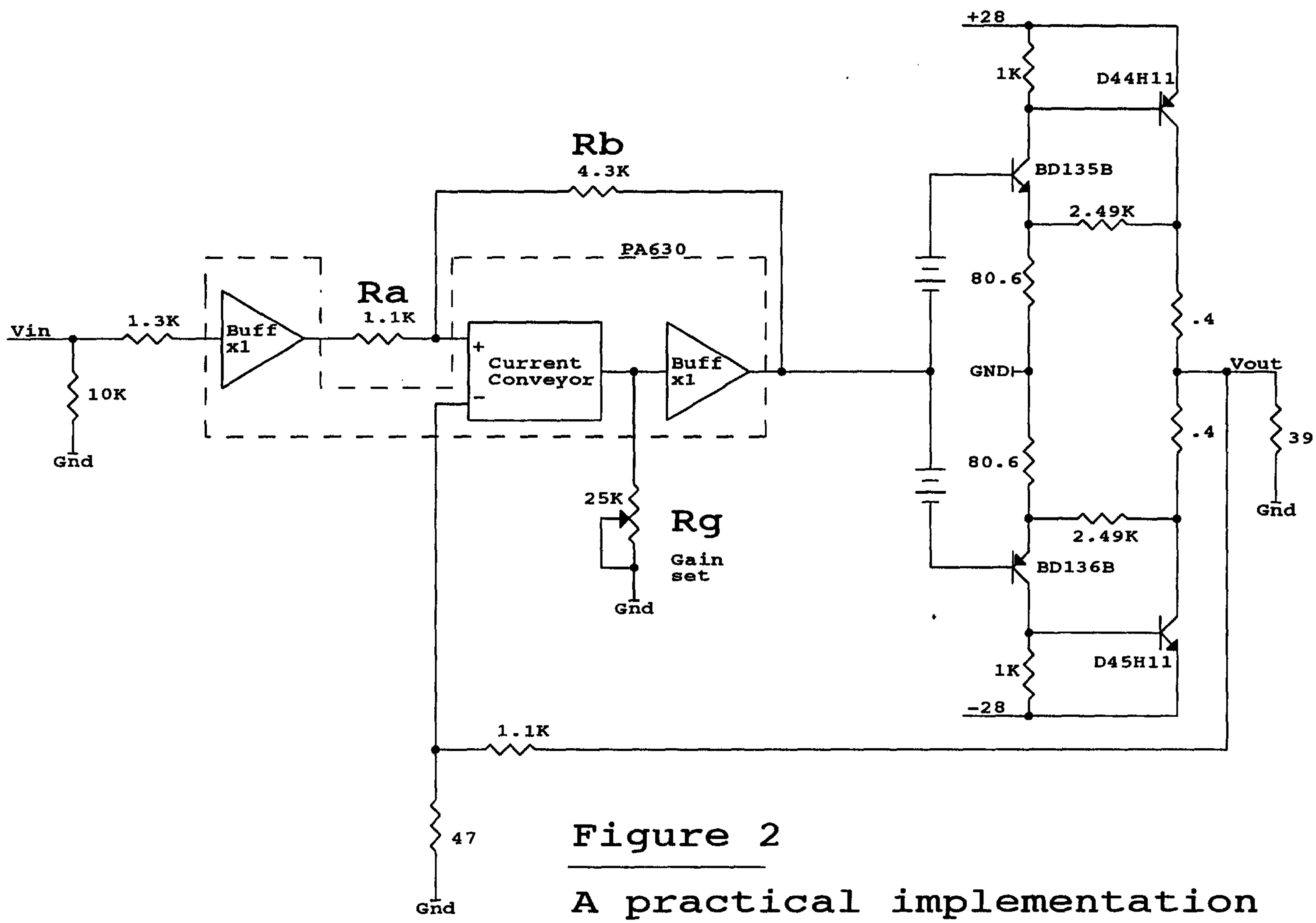

Figure 2

A practical implementation

Figure 3, THD+N(%) vs Freq(Hz) @ 6Vrms output. Lower curve is with Rb (Fig.2).

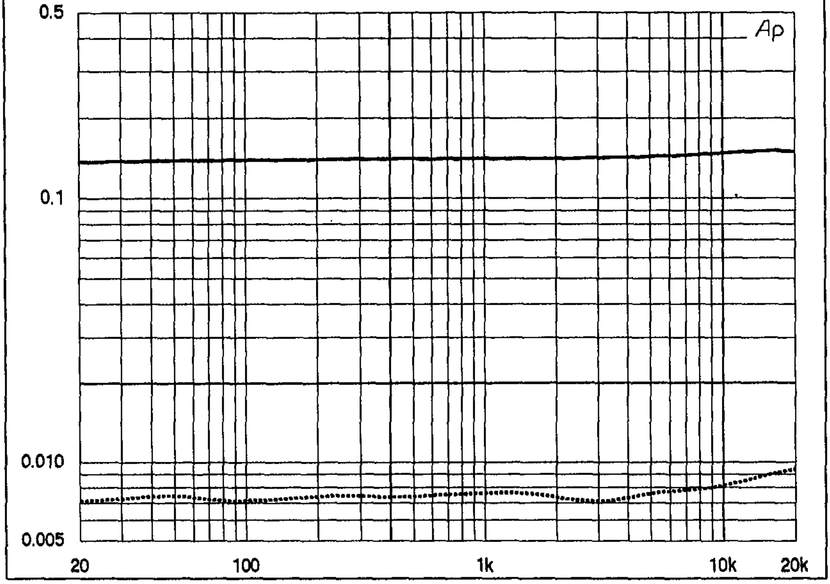

Figure 4b, Harmonic spectrum in dB re 6Vrms, 3kHz output. Rb (Fig. 2) inserted.

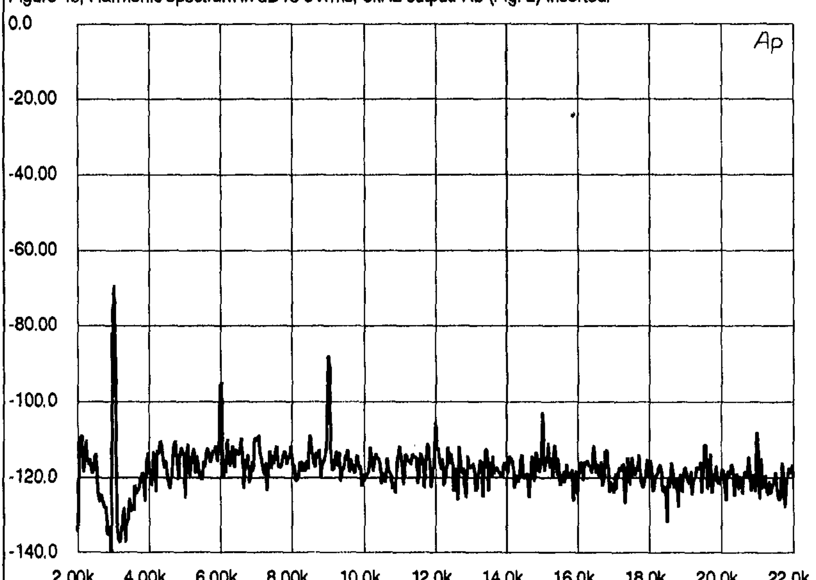

Figure 4a, Harmonic spectrum in dB re 6Vrms, 3kHz output. Rb (Fig. 2) removed.

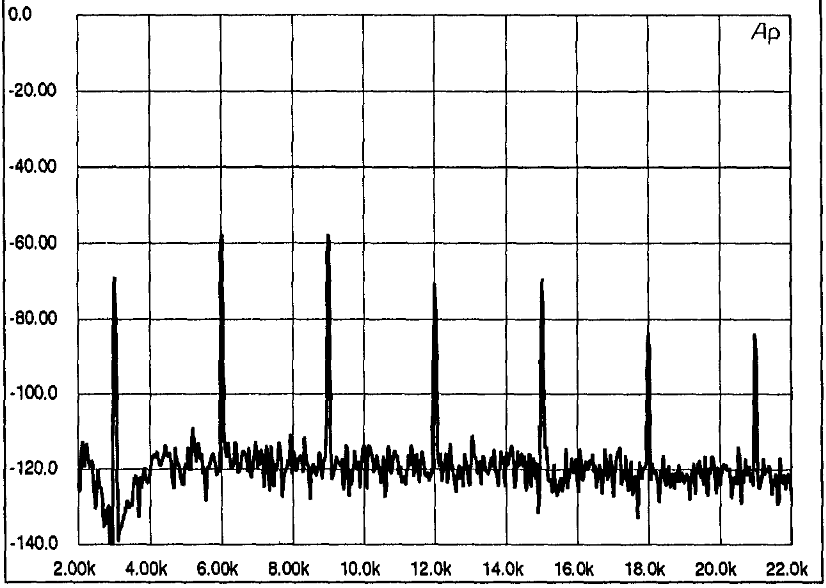

Figure 5, THD+N(%) vs Output level(Vrms). Lower curve is with Rb (Fig. 2).