Error feedback in audio power

In response to a plea for help on a feedback problem, William de Bruyn has unearthed three alternative methods of error feedback for power amplifiers that *do* work.

Following K H Ellis's plea for help in 'Feedback on Feedback' in the December 1996 issue, it seems to me that his amplifier (outlined later) was always bound to be unstable. Little or no attention seems to have been given to issues of loop stability.

Addition of the 22pF capacitor simply inserts a dominant pole at a suitable frequency; it does not 'filter' noise. The operational amplifier chosen for this implementation of Hawksford's error-cancelling idea is not particularly suitable as the inherent slew rate limitations of the device restrict the potential bandwidth.

There has been a number of practical amplifier designs which have used the idea of an error feedback loop around the output stage of an amplifier.

First is a design by E. M. Cherry, which deals with a number of issues rather elegantly. Quiescent current is sensed and controlled without any need for complex schemes of thermal feedback. Such schemes bring with them the difficulties of dealing with all of the thermal/electrical time constants.

Prof. Cherry's approach to this problem – the feedback loop around the back-to-back differential pairs – also permits accurate setting of the gain of the output stage to some desired level.

His concept of nested differentiating feedback loops achieves unconditional stability with high levels of feedback and very low distortion within the audio band.

A further amplifier of note is designed by Robert Cordell. It was published in 1983 and reprinted in the *Journal of the Audio Engineering Society*, Vol. 32, No 1/2, 1984, Jan/Feb.   www.keith-snook.info

This amplifier employs a simple method of feed-forward error correction based on Hawksford's scheme. The error-correction loop uses only two fast small signal transistors and the resulting improvement in transfer linearity is quite remarkable. Most of the crossover and transfer artefacts, that so much recent correspondence has concerned itself with, become relatively minor issues.

This design is capable of extremely low distortion over a very wide frequency band – less than 0.001% from 20Hz-20kHz. It also exhibits extraordinarily good high-frequency and transient performance and achieves a slew rate of more than 300V/µs.

The third amplifier is a commercially produced design, namely the Tandberg *3009A*. This also uses a variant of Hawksford's scheme. In this case no overall feedback is applied, each stage relying on local feedback for setting of overall gain. In this instance , the output stage used Hitachi mosfets. These fets are distinguished from *Hexfet* structures by their substantially lower transconductance and threshold voltages. This Amplifier is capable of good high-frequency performance.

All in all, I feel that much of the rather heated debate regarding the linearity of igbt devices as opposed to mosfets, 'batwing' transfer curves, etc. is rather absurd and has more to do with what people grasp with their hands
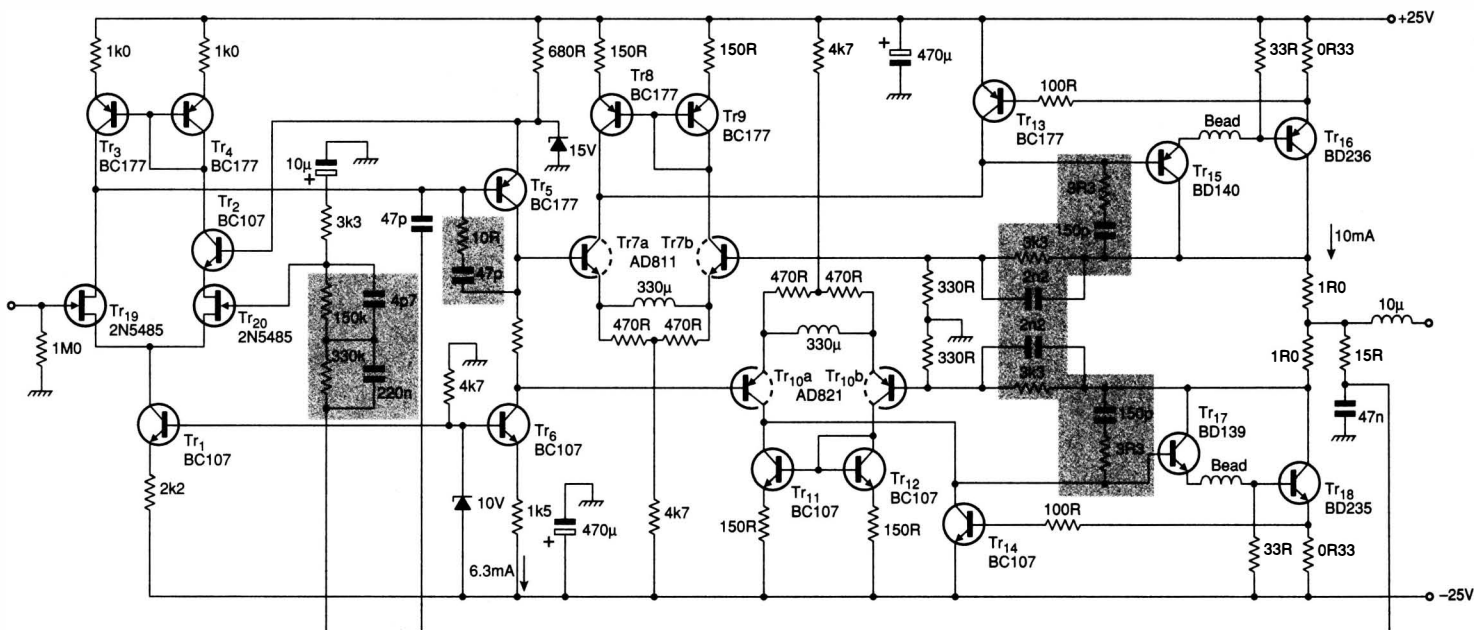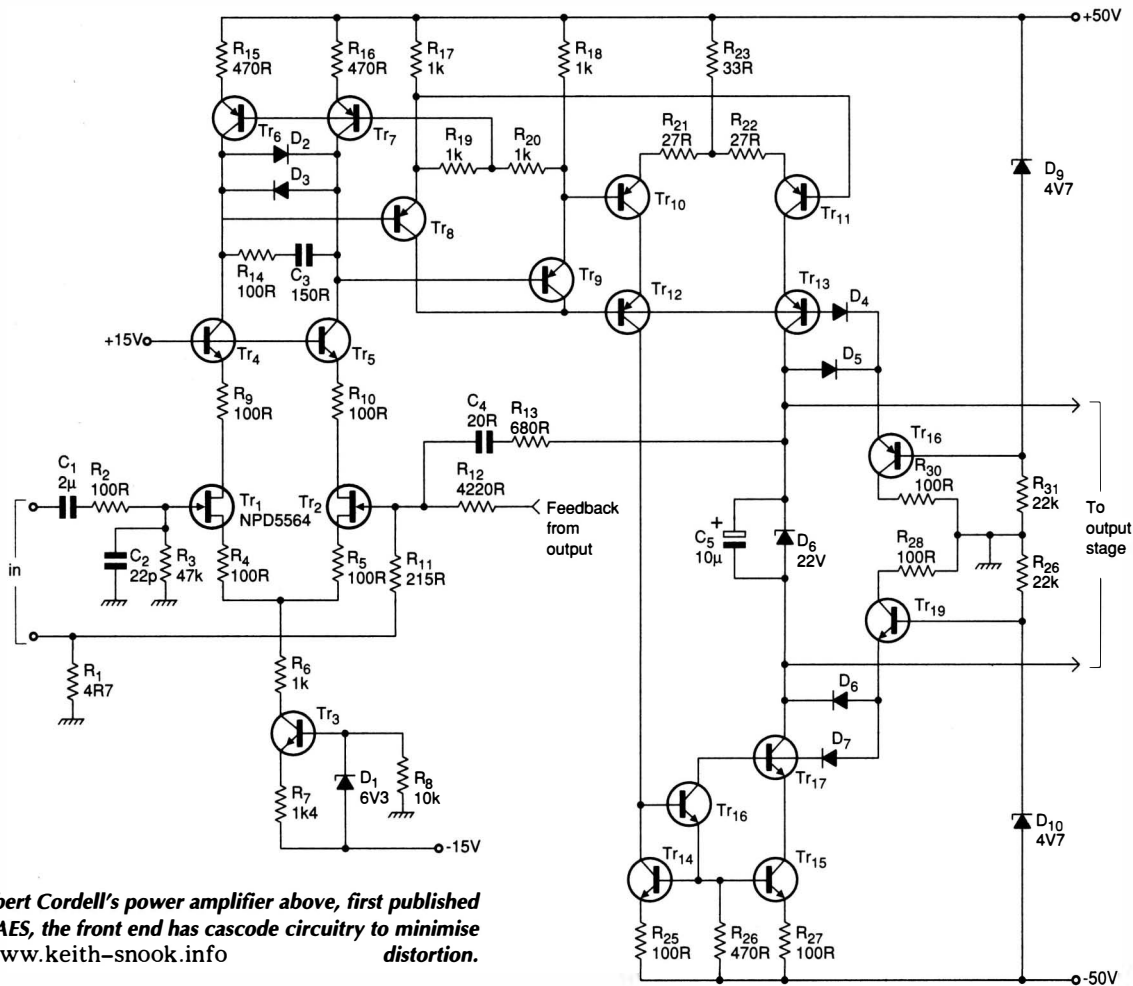

Fig. 1. Ed Cherry's 15W, 15Ω power amplifier, first published in IREE transactions, nested differentiating feedback loops are used. Note the driver circuit with inherent quiescent current regulation and substantial local feedback around the output stage.

In Robert Cordell's power amplifier above, first published in JAES, the front end has cascode circuitry to minimise distortion.

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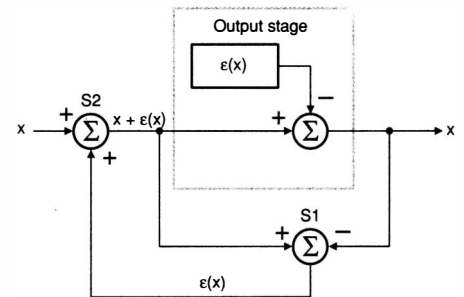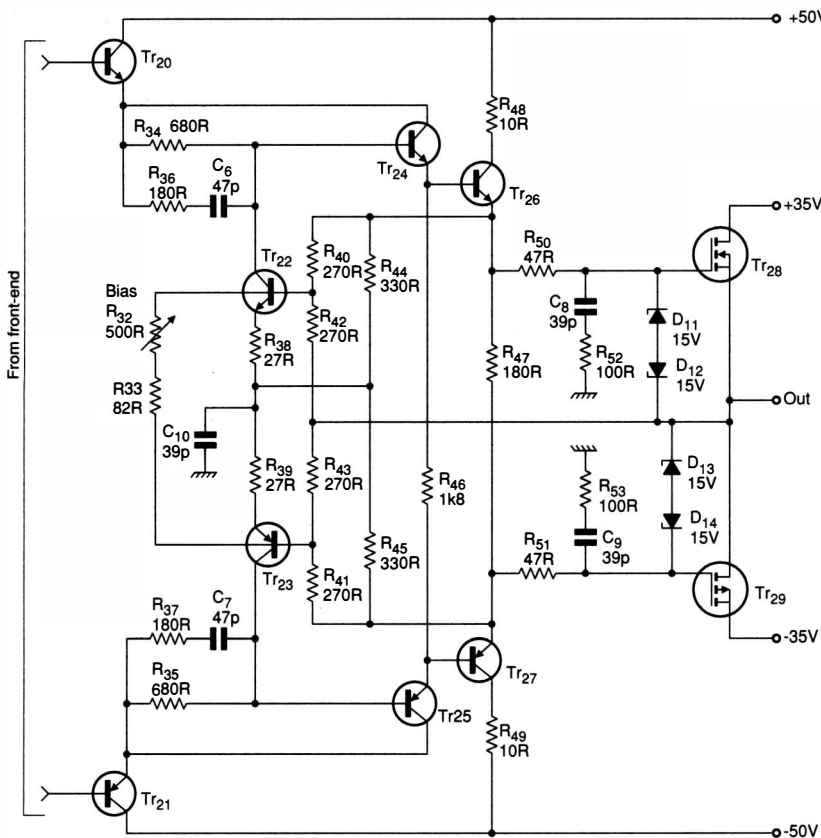
Error correction concept, above, for Cordell's power amplifier output stage, left, in which Tr_{22} and Tr_{23} provide the error correction.
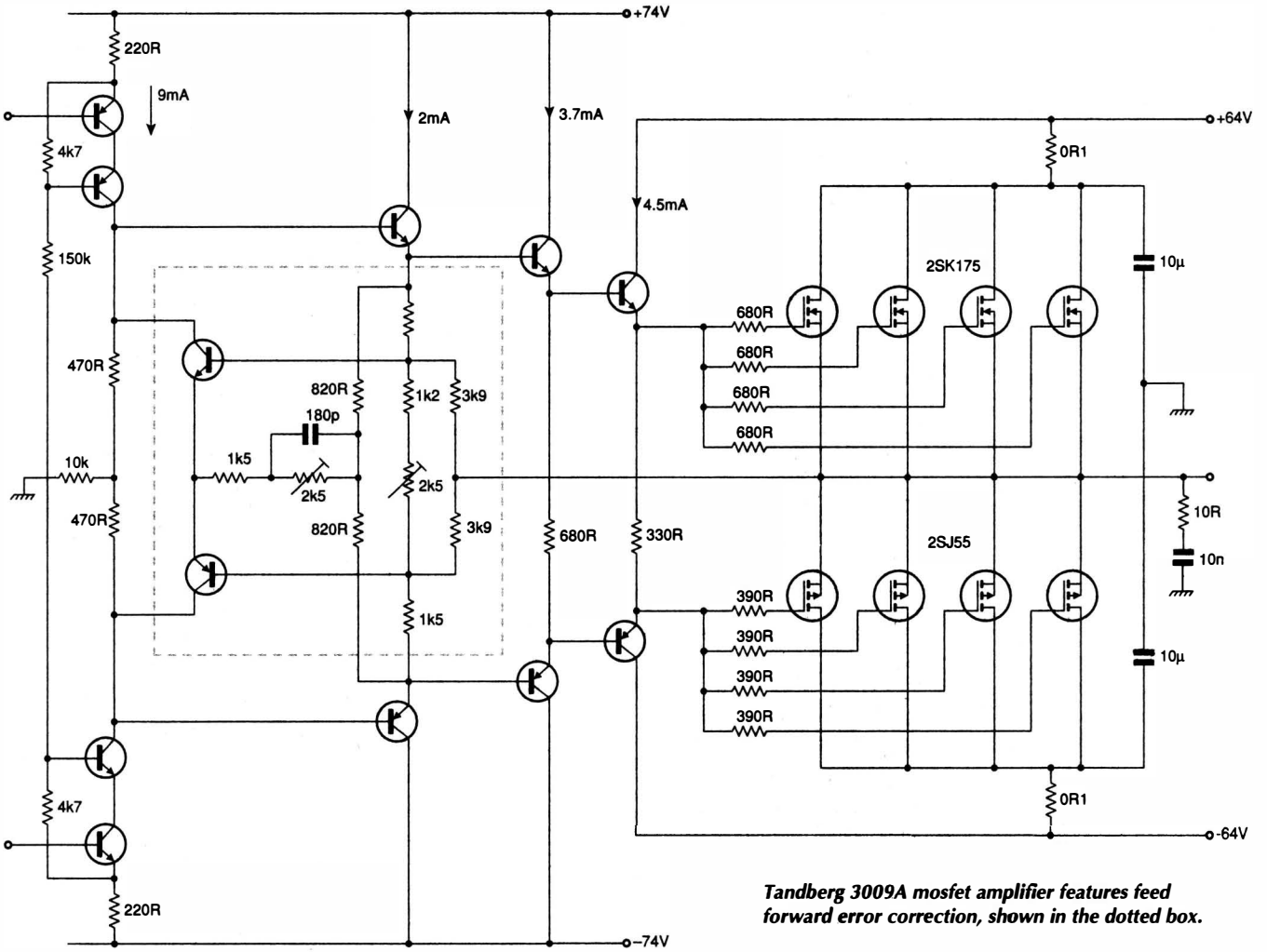
rather than with their minds.

As many of the problems associated with amplifier design seem to centre on achieving ever greater bandwidth, it seems – to me at least – that the fastest available devices are the preferred option.

Poor transfer linearity can be readily dealt with by applying some sort of error correction around the output stage, without the problems of dealing with all of the poles that the application of overall feedback has to contend with.

I would be pleased to see someone apply some form of error cancelling feedback loop around, say, a valve amplifier output stage. Such devices are inherently less linear than mosfets and have much lower transconductance than any solid state device.

+74V

220R

9mA

4k7

150k

470R

2mA

3.7mA

4.5mA

+64V

0R1

10μ

2SK175

680R

680R

680R

680R

10k

470R

1k5

820R

180p

2k5

820R

1k2

3k9

2k5

3k9

680R

330R

2SJ55

390R

390R

390R

390R

10R

10n

10μ

1k5

4k7

0R1

220R

-64V

-74V

Tandberg 3009A mosfet amplifier features feed forward error correction, shown in the dotted box.
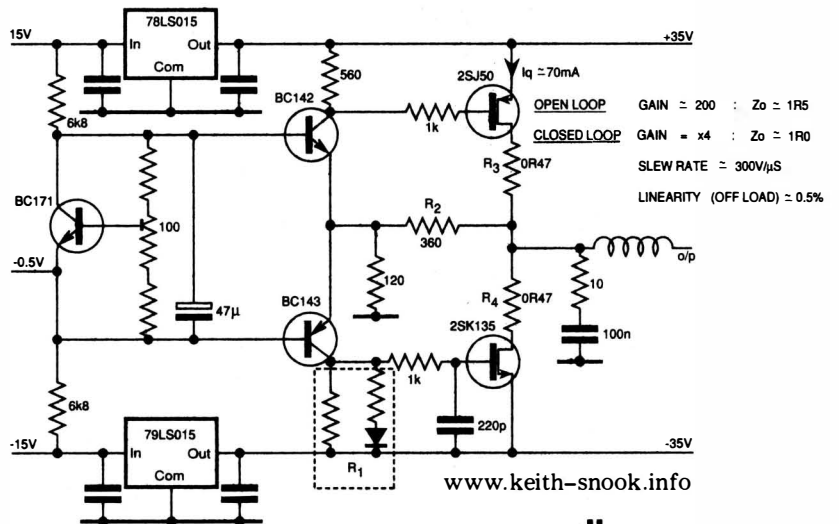
Extract from Ellis's original query

...applying negative feedback to give a gain of four, the stage shown gives reasonable performance, except that output impedance is about 1Ω. Also, when loaded, the stage distorts because there is nothing to increase the drive.
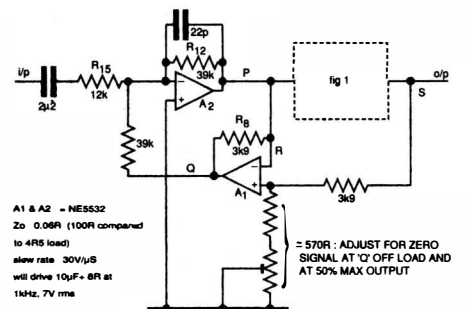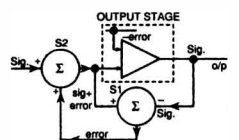
I was about to give in when I came across a reference to an error cancelling technique by Hawksford. The small diagram below gives the theory. Having got the gains right, the results were astounding.

During testing, I found that a capacitive load of more than 22nF caused a high output at high frequency. This was a surprise as the output stage itself would happily drive a 10μF at 1kHz. More experimenting gave the feeling that this was not parasitic oscillation, but rather amplified and filtered noise. While loading the output with increasing values of capacitor, the output of A_1 became increasingly noisy until it burst into oscillation at about 2MHz. Putting a small capacitor across R_8 (A_1) stopped the oscillation but was not the best place as only the error signal was being filtered. The best solution was a 22pF across R_{12} (A_2) to filter signal and error. The amplifier now drives 10μF with no problem.

I would welcome your comments.

15V

78LS015

In   Out

Com

+35V

560

BC142

2SJ50

Iq ≈ 70mA

6k8

1k

OPEN LOOP   GAIN ≈ 200 : Zo ≈ 1R5

CLOSED LOOP   GAIN = x4 : Zo ≈ 1R0

R_3 0R47

SLEW RATE ≈ 300V/μS

LINEARITY (OFF LOAD) ≈ 0.5%

BC171

-0.5V

100

R_2

360

o/p

BC143

120

R_4 0R47

10

2SK135

47μ

100n

6k8

1k

220p

-15V

79LS015

In   Out

Com

-35V

R_1

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TI Texan output stage, top, before a practical implementation (below right) of Hawksford's error-cancelling idea, below left, was added.

OUTPUT STAGE

error

Sig.

S_2

Sig. +

Σ

S_1

sig+
error

Sig. −

Σ

o/p

error

i/p

2μ2

R_{15}
12k

22p

R_{12}
39k

P

fig 1

o/p

S

39k

A_2

R_8
3k9

R

Q

A_1

3k9

A1 & A2 = NE5532
Zo 0.06R (100R compared to 4R5 load)
slew rate 30V/μS
will drive 10μF+ 8R at 1kHz, 7V rms

≈ 570R : ADJUST FOR ZERO
SIGNAL AT 'Q' OFF LOAD AND
AT 50% MAX OUTPUT