Letters to the Editor

The Editor does not necessarily endorse opinions expressed by his correspondents

Feedback amplifiers

Following the interesting and informed article by Mr Walker on low noise amplifiers (*Wireless World*, May 1972) there has been a protracted and inconclusive series of letters discussing the various merits of shunt and series feedback connections with regard to noise and distortion.

I would almost certainly have been happy to let this die out in its own way had not the discussion gone completely off the rails in John Linsley Hood's letter "Feedback Amplifiers" in the May 1973 issue.

Mr Linsley Hood suggests that the difference between the series and shunt feedback connections in the circuit given arises because in the series feedback case the signal is not normally attenuated much between source and amplifier, whereas in the shunt feedback case it will be attenuated 4-6dB depending on suitable operating parameters.

The effect of a finite input impedance in a feedback amplifier can be considered as a reduction in loop gain, and for the two connections, see Fig. 1, the effect of input impedance are as below.

Series feedback:

$$\frac{E_0}{E_1} = A(s)\left[\frac{R_e + R_{fb}}{(R_e + R_{fb})\left(1 + \dfrac{R_e + R_s}{R_{in}}\right) + A(s)R_e}\right]$$

When $R_e = R_s$ and $R_{in} \rightarrow \infty$, $A(s) \gg 1$

$$= \frac{R_e + R_{fb}}{R_e}$$

Shunt feedback:

$$\frac{E_0}{E_1} = -A(s)\frac{R_{fb}}{(A(s)+1)R_s + R_{fb}(1 + R_s/R_{in})}$$

In the limit $R_{in} \rightarrow \infty$, $A(s) \gg 1$

$$= -\frac{R_{fb}}{R_s}$$

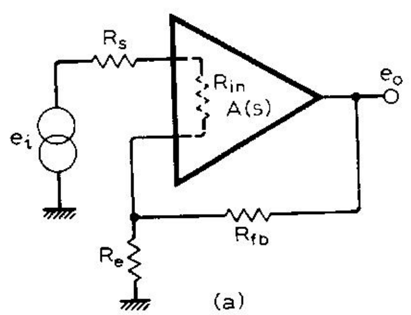
It can be seen that the sensitivity of the two circuits to finite input impedance is similar, with suitable values, e.g. a loop gain of 500 $R_{in} = 15\text{k}\Omega$, $R_s = 50\text{k}\Omega$, $R_{fb} = 500\text{k}\Omega$, the reduction in gain in each case by considering R_{in} finite is: series 1.3dB, shunt 0.8dB.

It is not correct to assert that the intrinsic problem with a shunt feedback amplifier is that its input impedance attenuates the signal by 4-6dB. It is readily seen from the equation that the input impedance becomes insignificant anyway when $R_{in} \rightarrow R_s$ and completely insignificant for $A(s) \gg 1$. It is therefore simply a problem of good design to assure that R_{in} is a suitable value, not a drawback of a feedback connection.

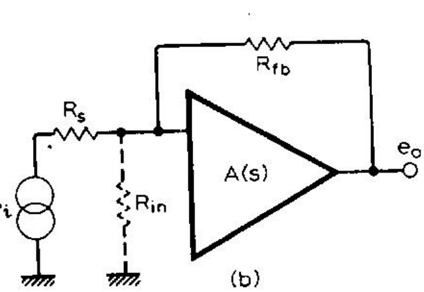
Mr Linsley Hood goes on to say that (in the shunt feedback case) the noise impedance seen by the input is not the input resistor circuit value but the value of the "virtual earth impedance", and suggests that this impedance is 600–1200 ohms. This comment is quite amazing. What is a virtual earth impedance? One can only assume that it is a phantom idea to describe how "earthy" the virtual earth point is.

It is quite misguided to use this idea. The virtual earth is a phenomenon resulting from the feedback connection but it does not have an impedance as such that can generate noise.

A shunt feedback amplifier is a current amplifier, and the low noise condition is with the input open circuited, i.e. in Fig. 1(b) the generator E_1 is open-circuited. The noise of the amplifier here is determined by the thermal noise current generator in R_{fb} and the noise factor of the amplifier with a source resistance of R_{fb}.



(a)



(b)

In its mode of use (E_1 short circuited) the source resistance is $R_s//R_{fb}$ and the noise current of R_s is significant. Certainly a 47kΩ source resistor will generate a noise voltage of 3.9μV and provided the input is short circuited this will be shown in the amplifier noise performance.

In the case of the pickup amplifier R_s = 47kΩ, $Z_{fb}(s) \gg R_s$ it can be shown by calculations that the maximum s/n ratio with a cartridge connected is 58dB ref. 2mV.

Experiment and theory clearly show a marked increase in the noise of such an amplifier when the input is short circuited. Perhaps Mr Linsley Hood could explain how connecting a 47kΩ resistor in parallel with a 1000Ω virtual earth impedance can give a 10dB rise in noise?

Finally, on the subject of distortion, good circuit design can easily permit a series feedback amplifier to have a repeatable performance of s/n better than 70dB s/c ref. 2mV and distortion less than 0.01% in the audio range. The fact that this cannot be achieved with a 741 should be considered irrelevant by any engineer concerned with these and any other important design parameters not covered in the arguments to date.

J. R. Stuart.
Leeson Audio Ltd.,
St Ives,
Huntingdon.

May I offer the following points regarding recent correspondence on distortion and noise?

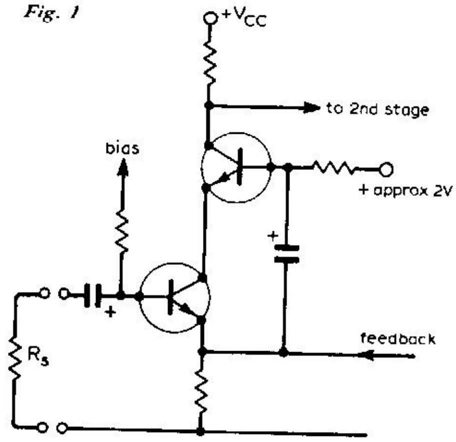
(1) "Common-mode distortion". In many cases of practical interest, it is the variation of C_{cb} of the first transistor with V_{cb} (Early effect) which dominates. Considering a BC214 input stage run at V_{ce} = 5 and handling an input of 1 volt r.m.s., the Texas data sheet indicates a capacitance swing of 3pF. This corresponds to a second harmonic distortion of 0.1% at 20kHz if the source impedance is 10kΩ. A considerable reduction in Early effect distortion, and almost complete elimination of the other distortions which are not amenable to reduction by feedback, may be obtained by using a bootstrapped cascode arrangement (Fig. 1).

There is now an Early effect from the upper transistor's C_{cb}, but it is much less than before since it injects distortion into the output, not the input. In fact if the quiescent current through the transistors is chosen for optimum noise figure from R_s, then the Early effect will be reduced by a factor $\sqrt{\beta}$. This circuit permits the lower transistor to be run at a very low V_{ce}, for optimum noise performance, without compromising the ability to handle large signals.

(2) Reduction of distortion by feedback. The statement by Mr Hood and quoted by Messrs Mornington-West and Vereker (May issue), that quadrature components of the feedback are ineffective in reducing the distortion, is absolutely without foundation, as is shown in the appendix to this letter.

To understand the poor high frequency performance of Mr Linsley Hood's *Hi-Fi News* design it is sufficient to consider how much feedback is applied round the output

Fig. 1

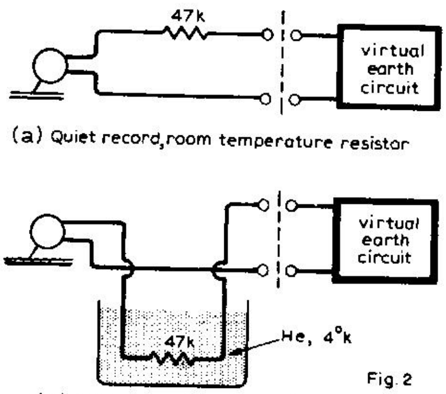


stages. Apart from the usual local feedback, it amounts to $5\frac{1}{2}$dB at 20kHz.

It is not nowadays safe to assume that the effect of a "h.f. stabilising capacitor" is confined to high frequencies. In the design mentioned above, the dominant lag capacitor looks harmless enough at 220pF, yet it gives an open-loop break point of 10Hz.

(3) The measurements reported in Mr Linsley Hood's second letter in the May issue point to interesting possibilities in noise reduction.

Consider a notional dividing line between the 47kΩ resistor and the rest of Mr Linsley Hood's virtual earth circuit (Fig. 2 (a)). The combination on the left will, as he says, produce an open-circuit noise of 3.9μV.



(a) Quiet record, room temperature resistor

Fig. 2

(b) Noisy record, cooled resistor

Now let us take a gramophone record on which, by some mischance, tape hiss has been recorded, and let us choose a pickup of the right sensitivity so that this hiss appears as exactly 3.87μV on its output terminals. Pickup and resistor will then produce $\sqrt{3.9^2+3.87^2} = 5.5\mu$V of noise, but if we now immerse the resistor in a dewar of liquid helium (Fig. 2 (b)) the open circuit noise will once again be 3.9μV.

The impedance presented to the circuit on the right is of course exactly the same for Fig. 2 (b) as for 2 (a), so it should need only a little fiddling of the frequency spectra to convince the circuit that it is connected as in Fig. 2 (a), when the truth is 2 (b). If now the circuit can achieve the noise value of 0.6μV claimed by Mr Linsley Hood, then a noise reduction of $20\log_{10}\frac{3.87}{0.6} = 16.2$dB will have been obtained.

Perhaps some enterprising record company will consider this technique for revitalising its pre-Dolby LPs?

Peter G. Craven,
Oxford.

Appendix

Let the amplifier have perfect common mode rejection so that V_{out} is a function of V_1 only. Suppose that we are trying to reproduce a sine wave of unit amplitude and that it is possible to predistort V_1 so that V_{out} is a pure sinusoid. Let "X" be the assumption that the gain of the system to a small signal superimposed on the input is not greatly affected by the presence of the large signal. X will be false if the amplifier is near to clipping.

Let the gain (V_{out}/V_1) of the amplifier at the ith harmonic of the sinusoid be A_i and let β_i be the corresponding feedback factor (V_f/V_{out}). To take account of phase shifts, A_i and β_i will be complex. Suppose that we have succeeded in making V_{out} a pure sinewave and that d_i (also complex) is the amplitude of the ith harmonic of the predistorted signal V_1 necessary to achieve this. Since the feedback network is assumed linear, V_f will be a pure sine wave, and since $V_{in} = V_1 + V_f$, it follows that V_{in} must also have an ith harmonic of amplitude d_i.

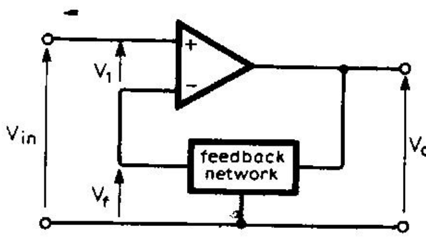
We wish to consider a pure V_{in}, and this we get from the predistorted V_{in} by adding $-d_i$ of the ith harmonic for $i = 1 \ldots \infty$. By assumption X there will appear harmonics at the output, the amplitude of the ith being $-G_i d_i$, where G_i is the gain of the system (including feedback if any) at the ith frequency.

Since d_i does not depend on the feedback, we have proved the well known fact that feedback reduces each distortion product in the same ratio as it reduces the gain at the frequency of the distortion product.

By elementary feedback theory, G_i is given by

$$G_i = \frac{A_i}{1+A_i\beta_i},$$

and comparing with the case $\beta = 0$, it is clear that introducing the feedback has reduced the gain, and hence the distortion



by a factor $|1+A_i\beta_i|$. This factor we now evaluate for an amplifier with a loop gain of 10 ($|A_i\beta_i| = 10$).

No phase shift → $A_i\beta_i$ is real and positive
→ $|1+A_i\beta_i| = 11$

90° phase shift → $A_i\beta_i$ is pure imaginary
→ $|1+A_i\beta_i| = 10.05$

180° phase shift → $A_i\beta_i$ is real and negative
→ $|1+A_i\beta_i| = 9$

Mr Linsley Hood replies:

I am sorry that Mr Stuart feels that the debate on feedback amplifiers "has gone completely off the rails", but he has taken my letter somewhat out of its intended context.

To refer specifically to the main point of this—measurements suggest that the s/n ratio of an amplifying circuit with shunt f.b. is a few dB worse than in the case of the series f.b. circuit with the same value of input resistance.

I believe that this phenomenon is real, and that it is due to the fact that any real amplifying device will require some input energy—significant in a bipolar transistor—and that in the shunt circuit this is obtained from the input signal.

In the latter part of my letter I suggested an alternative method of considering the noise impedance seen at the input—which is a voltage node—in a shunt f.b. amplifier. If one considers the amplifying element, having a known open loop gain, as being detached from the feedback loop but amplifying the noise voltage seen at that point, the noise impedance of the "virtual earth" can be derived, if one is interested to do this.

This observation was not specifically related to the s/n ratio of a shunt feedback circuit, which is best approached by considering it as a current amplifier. In this case the input noise currents decrease as the root of the admittance ($1/Z$) of the input limb, whereas the signal current decreases linearly. Other things being equal the lower the input limb impedance, the better.

In the particular case of a pickup amplifier circuit with R.I.A.A. equalisation, it should be remembered that the effective noise bandwidth is only about 500Hz. Since this allows a s/n ratio with a 47kΩ input resistor and a shunt f.b. circuit to be −72dB ref. 5mV (−64dB ref. 2mV) I suspect that the "calculations" to which Mr Stuart refers assume a wider bandwidth than this. The relative advantage of the series circuit diminishes with frequency when used with an inductive element such as a magnetic p.u. cartridge, from about 11dB at 1kHz to some 3dB at 5kHz. (Assuming a 600mH cartridge inductance, and a series f.b. input d.c. resistance of 2kΩ).

In reply to Mr Craven, on the more important point of the extent of distortion reduction by feedback at phase angles other than 180°, the problem is that the predicted distortion reduction from the formula

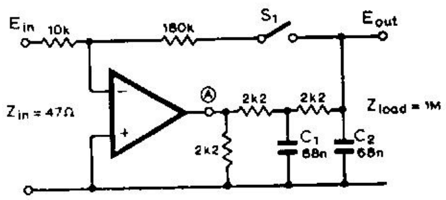
$$\frac{D_F}{D} = \frac{A_F}{A}$$

gives unsound results under these conditions, whether the gain is calculated by the method Mr Craven shows or whether it is derived by the classical formula below.

$$A_F = \frac{A}{\sqrt{1+|\beta A|^2 - 2|\beta A|\cos\Phi}}$$

where Φ is the f.b. phase angle.

As an example, a non-linear amplifier element, having a gain of 100×, an input impedance of 4.7kΩ and a t.h.d. of approximately 4% at 1kHz and 1.5 volts r.m.s. output, was set up as shown in the figure, with an output lag circuit whose values were chosen to give a phase lag of 90° at 1kHz.



When S_1 was closed, to apply "negative" feedback (10dB at 20Hz, although the gain reduction was only 2dB at 1kHz) the t.h.d. at 1kHz increased from 4.7% to 6.3%. However, when the phase shift introducing elements (C_1 and C_2) were removed, closure of the switch to introduce true negative feedback reduced the t.h.d. from 4.1% to 1.3%, which is in line with theory. In both cases, when feedback was applied, the input to the amplifier was increased to give the same output at point "A" (1.5V r.m.s.) as in the no-feedback case.
J. L. Linsley Hood,
Taunton,
Somerset.

Car seat belts

As a campaigning member of the relatively small percentage of seat-belt wearing drivers, I nevertheless must add a note of protest against the gleeful hand-rubbing in anticipation of forthcoming contracts which formed the basis of Vector's article in the May issue on the proposed automatic seat belt interlocks involving the use of i.cs.

The i.c. boys have indeed "got it made" as he suggests, and advantage will doubtless be taken of the opportunity to scale new heights of technological overkill with the machines on which many are obliged to depend for personal transport. One needs only to observe the panic of the visitor to London when confronted with automatic ticket barriers at tube stations to judge the total inadequacy of the non-technical majority when faced with mechanisms which demand a specific sequence of human responses in order to perform their function.

I realise that humans adapt gradually to the numerous complexities of modern living, but have you ever tried to fasten an American 3-strap seat belt while lights flash and a mind-numbing buzzer sounds? The experience is the most persuasive inducement to leaving the belts permanently locked behind the seats.

Quite apart from this, many people firmly believe that the individual should retain the right to be hurled through the windscreen of his car at will, and that the burden of his personal safety in this instance should neither be shifted to the already over-intrusive state, nor to the already overworked police force.

Any safety regulations and technological advancements which prevent an individual from endangering others must be applauded, but regulations covering personal safety could never be far-reaching enough to be 100% effective, and until such time as you produce a solid-state system as a substitute for the human brain — there will always be a man prodding wires into an electrical socket with matchsticks, leaping from a bus into the traffic stream, and refusing to wear his seat belt.
Lyn Heigl,
Studley.
Wilts.

Magnetic units

I am much obliged to Dr McCaig for replying in the June issue so informatively, direct from the Permanent Magnet Association at Sheffield, to my articles on magnetism (Jan. and Feb. issues). (At least the P.M.A. hasn't made complete nonsense of my criticism directed at Sheffield by having moved, unknown to me, to Bognor Regis or Lerwick, in keeping with the trend towards dispersal.) My apology is due to the P.M.A. for my having suggested that it, like the incredible referee cited by Dr McCaig, is still unaware of SI units. I do, however, remind readers that my technique of trailing my coat provocatively in order to elicit information is or should be well known by now. And I wish Dr McCaig had made clear what practice has been continued in the majority of P.M.A. publications during the last 20 years. Listing permanent magnet properties in m.k.s. as well as c.g.s. units? If so, it would seem to be as if our Government were to continue for the 20 years after 1971 to give money values in decimal units as well as £.s.d. In short, not much encouragement to make the effort to change over. Which may be one reason why the majority of papers on magnetism continue to use c.g.s. units. (This was actually my essential grouse.) And what units do individuals within the P.M.A. normally use?

However, assuming that the P.M.A. collectively and individually is doing all it reasonably can to encourage abandonment of c.g.s., with renewed apologies to it, I hereby amend my strictures by altering the address of the target from Sheffield to all those places where people use c.g.s. units without reasonable excuse. In this at least I would seem to have the influential backing of Dr McCaig.

Although I'm not altogether convinced that standardizing the unit and symbol for "intensity of magnetization" (or whatever) would make all the difference to acceptance of SI units by workers in magnetism (surely the question arises with any system of units?), I'm at one with Dr McCaig on the desirability of tidying up here. In so far as I have used this quantity (and that is not at all far, as I shall explain in a moment) I have used the symbol M, but I would happily accept J if that is decreed; in fact, I'll accept it now, for although there is unlikely to be any confusion with mutual inductance they do both come into related contexts. And my preferred unit is the tesla, since from a practical point of view one can regard J as the difference between the actual flux density and the corresponding flux density *in vacuo*, both of these being in teslas. But I take Dr McCaig's point that if the chosen measurement technique makes it more appropriate to treat it as a kind of H by reckoning it in A/m, fair enough.

Finally, I must reply to the charge that I ignored the need for the quantity J. I plead guilty. But without remorse. For Dr McCaig is a physicist and represents magnet manufacturers. I am an engineer and, for the purpose under discussion, purport to represent consumers of magnets among a great many other things. So it is hardly surprising if the attitudes to J are quite different. I don't for a moment doubt that to the people Dr McCaig represents J is, as he says, fundamental. Under a disguise, for readers who I assumed were interested in the theoretical physics of magnetism, I myself once found it necessary to introduce J (as M). But I very much doubt that it is a necessary or desirable part of an elementary 7-page treatise on magnetism and magnets for readers to whom this subject is incidental. I've never once needed J to deal with practical problems roughly within the field covered by *Wireless World* — in which of course the word "Wireless" is rather like the "candles" allegedly brought into the House of Commons when it is too dark for Hon. Members to see their order papers clearly. It is interesting to note that although the physicists Bleaney and Bleaney in their substantial volume *Electricity and Magnetism* (using m.k.s. units) deal with J (as M, which is probably where I got it) in the standard theory, they hardly mention it in the sections on magnetic measurements. And in Hvistendahl's book on units, J (or anything like it) and susceptibility are not mentioned. But then he is an engineer.
"Cathode Ray."

Printed circuits the easy way

Most people who have attempted printed circuit work of a one-off nature will admit this can be time consuming and tedious using the normal method of draughtsman's pen together with either brushing Belco or Humbrol as a resist. It requires considerable artistic acumen or the patience of a saint!

This chore finished and drying time allowed, one has then to wait somewhere between 25 and 50 minutes while surplus copper very slowly dissolves in the etching fluid.

The result of all this time and trouble ought to be a neat web of sharp unbroken lines and sensibly circular drilling points, not the sorry bodge which frequently causes the experimenter to revert to tag board or pin board.

There had to be an easier way and out of sheer frustration the following was evolved. Instead of the draughtsman's pen and Belco a fibre tipped waterproof marker pen costing about 22p, called the 'Miracle Pen' (of Japanese origin) was adopted and is a delight to use, producing fine or thick lines with ease. (A 1in × 1½in board took 10 minutes to draw, drill and etch.) Virtually no drying time is required. The pen is refillable, but should last a considerable time provided the cap is replaced when not in use. For professional looking numbering and lettering the self adhesive 'Letraset' used as a resist has proved most effective.

All that remained was to speed up the etching. Apparently some form of effective agitation was required. Eccentric cams were suggested for wobbling the tank but just appeared to cause swirl; supersonic agitation was obviously out for kitchen use. The answer proved to be aeration; this was easily and cheaply provided by an electric aquarium air-pump costing £1 together with a porous air-stone at 5p to disperse the bubbles. A glass water jug, narrow at the bottom and wide at the top, was half filled with a strong solution 60/40 ferric chloride plus 2cc hydrochloric acid*. This is diluted with an equal quantity of water. The jug was placed in a polythene washing-up bowl full of fairly hot water in order to warm the solution the air-stone was placed at the bottom of the jug and connected by its tubing to the aerator.

When switched on, due to the "Vee" shape of the tank, even dispersion of bubbles throughout the fluid was observed. The work to be etched was then suspended in the fluid, etching was completed in five minutes.

Rinse under the cold water tap to remove etching fluid, then remove resist with rag well moistened with cellulose thinners. A final rub with Brasso and the process is complete.

Should you make a mistake when drawing the circuit a rag moistened with cellulose thinners can be used as an eraser.

One other point I feel worth mentioning. After assembly and soldering it is worth while rubbing over with cellulose thinners to remove untidy flux, then applying a coat of Ronseal thinned with slow cellulose thinners as protection.

J. Ferguson,
Penrith,
Cumberland.

*The chemicals used by the writer are dangerous and should be treated accordingly. Ed.

V.H.F. receiver performance

Isn't it time that some "figure of goodness" was instituted for v.h.f. receivers, other than the useless "locks in at $\frac{1}{2}\mu$ V" or whatever?

It is a revealing experience to try several different v.h.f. sets on the same aerial. The results — especially on stereo — go all the way from very good to ruddy 'orrible! Yet the specs give no hint at all as to which is which. Nor does a list of semiconductors give any indication.

I own two v.h.f. stereo receivers, one all-germanium with a stereo lock in of 5 μ V, lineup r.f.-osc/mixer-3 i.f.-ratio disc; the other all-silicon with a stereo lock in of $\frac{1}{2}$ μ V, lineup f.e.t. r.f. and mix-sep-o.s.c-2 i.c. (CA3012)-Foster-Seely disc.

Now which would you expect to be the best? The actual fact is the former! (Though I'm working on the latter.)

Point being that in an advertisement it would be the i.c. one which would seem to be the best.

Given a dozen units to choose from — how do you do it? Advice to "try" is absurd. Surely there should be some British Standard figure that could decide.

Ronald G. Young,
Peacehaven,
Sussex.

Amateur computer club

I feel that you and your readers may be interested to hear that, as a result of advertisement in your journal and other magazines last year, the Amateur Computer Club has been formed.

The club is for those interested in the construction, design or programming of computers as a hobby. At present the main activity is the production of a newsletter (which appears every two or three months) which acts as a databus to distribute information on hardware and software techniques of interest to the members.

Anyone interested in the club may receive further details from me at the address below (s.a.e. appreciated).

M. Lord,
7 Dordells,
Basildon,
Essex.

Power supply design

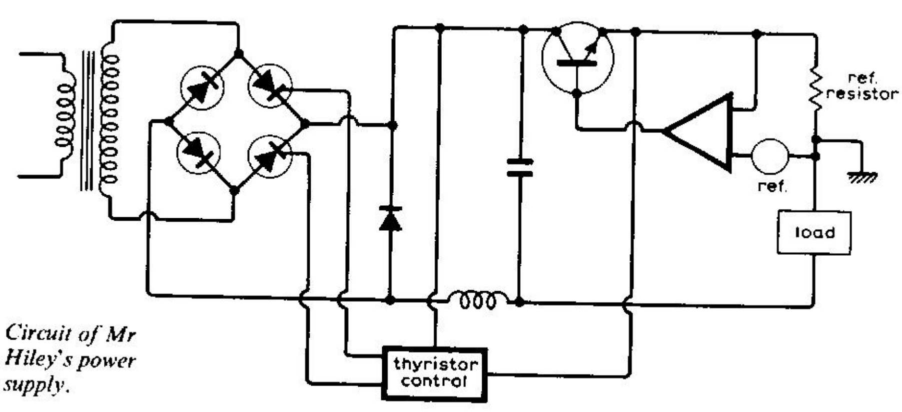
I was interested to read Mr R. Aston's article in the May issue. The idea of a switching pre-regulator controlling the voltage across the series element in the main control loop is not new.

Previous designs in my experience have mostly used thyristors operating at line frequency for the pre-regulator. I was myself involved in such a design for an ultra stable (5 p.p.m.) wide range constant current supply. For reasons of isolation this was operated from a 400Hz motor generator set, but our experience showed that it would operate equally well at 50Hz with suitable adjustment of smoothing components.

The arrangement shown below in the diagram was used. A similar system is to be found in power supplies manufactured by the Harrison Division of H.P. and elsewhere.

With the advent of modern power switching transistors an obvious modification to the above circuit would be their use in a switching pre-regulator. However, I was much discouraged in this line of development by the manufacturers (including Mr Aston's company) of commercial switching supplies who were not interested in my proposal for a system almost identical to Mr Aston's.

J. F. Hiley,
Bishop's Stortford,
Herts.



Circuit of Mr Hiley's power supply.

Audio amplifier design

I read with interest the letters on audio feedback-amplifiers published in the May 1973 issue (Letters pp. 246–248), and would like to comment on one or two of the points raised.

Messrs Mornington-West and Vereker make a useful point regarding the noise contributions due to later amplification stages. While I agree with their analysis, it may be difficult to apply the result in the case when stages are current rather than voltage driven.

This is the case for the second stage of the amplifier shown on p. 236 of my article on low-noise amplifiers (May 1972); I found that current driving gave better linearity in large-signal stages. For these conditions, emitter degeneration in the second stage is undesirable, and in any case major-loop feedback is preferable provided stability margins are met.

The noise contribution of the second stage is readily calculated using Faulkner's concept[1] of noise resistances, and since the second transistor is being current driven only the noise current generator need be considered. Its noise is transformed via the input transistor (a voltage to current converter) to a noise voltage source or series noise resistance at the input, of value:

$$R_{nv2} = g_{m2} \cdot \frac{(1+g_{m1} \cdot R_{e1})^2}{2 \cdot h_{FE2} \cdot g_{m1}{}^2}$$

Reference

1. Faulkner E. A. "The Design of Low-noise Audio-frequency Amplifiers", *The Radio and Electronic Engineer*", vol. 36, 1968, pp. 17 30.

Comparing this with the series noise resistance due to collector current shot noise in the input transistor ($R_{ne1} = 1/2 \cdot g_{m1}$), we see that for R_{ne2} to be negligible (say one tenth),

$$g_{m2} = \frac{h_{FE2} \cdot g_{m1}}{10 \cdot (1 + R_{e1} \cdot g_{m1})^2}$$

hence a ratio of collector currents of

$$\frac{I_{c2}}{I_{c1}} = \frac{h_{FE2}}{10 \cdot (1 + R_{e1} \cdot g_{m1})^2}$$

This is step 4 in the design procedure given in my article (p. 236).

In practice, the second transistor will contribute excess noise in its noise current generator so a good margin of safety is advisable in shot noise calculations. For the feedback triple given as the example, the second stage contributes a noise resistance of about 60 ohms which is negligible compared with the series resistors and noise resistance in the input circuit. The presence of flicker noise in the second stage may be detected by shorting the input of the amplifier, thus nullifying the effect of excess noise in the first-stage current generator.

I do not wish to reiterate the contents of my article or previous correspondence in connection with Mr Linsley Hood's reply to my April letter, but from a simple "ideal case" analysis it is clear that with a low-impedance source (e.g. a pickup cartridge) the parallel termination offers a very much better noise figure than the series resistor. This follows directly from the noise figure equation,

$$\text{N.F.} = 10 \log_{10}\left(1 + \frac{R_{series}}{R_{source}} + \frac{R_{source}}{R_{parallel}}\right) \text{dB}$$

and is independent of any attenuation due to finite input impedance of the amplifying device (intrinsic or otherwise).

In fact the attenuation of 4–6dB, quoted by Mr Linsley Hood, due to this cause, is quite incompatible with the achievement of an adequate noise figure which demands a common-emitter transistor input impedance several times greater than the source impedance, i.e. voltage drive conditions (Ref. 1, section 3.2). If he believes the input attenuation to be the problem, why does he not use a field-effect transistor?

When he refers to the "noise impedance" seen by the input does he mean the equivalent noise resistance? Consider a simple inverting operational amplifier of gain A with equal feedback and input resistors and with the input grounded. By summation of currents at the virtual earth, the noise output voltage is $\sqrt{4kT\Delta f \cdot 2R}$ giving a voltage at the amplifier input of $(4kT\Delta f \cdot 2R)/A^2$ mean square volts, or an equivalent resistance of $2R/A^2$. This disagrees with the virtual earth impedance of approximately R/A, the summing point in fact being quieter.

One would not expect the noise at the virtual earth to correspond to the noise voltage across the input resistor since the amplifier is sensing the currents flowing. The presence of a virtual earth (since it is due to n.f.b.) does not affect the noise figure of the input transistor which should be optimised under open-loop conditions (not for the virtual earth impedance) and the feedback used to alter the input impedance (Ref. 1, section 4.1). The virtual earth impedance does not enter into the noise calculations since it is a function of the open-loop amplifier gain which can be chosen arbitrarily from noise considerations.

H. P. Walker,
South Queensferry,
West Lothian.

I thank Mr Walker for his further letter, and concur in general with his comments.

I agree that a high input impedance device such as an f.e.t. would avoid the problem of input energy loss on voltage to current conversion. The difficulty is that the required input impedance for such a device, for optimum device noise figure, is in the megohm range, which is unsuitable for a low input impedance system.

J. L. Linsley Hood,
Taunton,
Somerset.

Distortion reducer

Mr Bollen, in the April issue (Letters, p. 192), has correctly pointed out a term which I omitted in my analysis of his Distortion Reducer. Nevertheless I should like to develop the idea that his system is essentially equivalent to the procedure of increasing conventional negative feedback around the main amplifier and adding a pre-amplifier.

The correct expression for the input to the main amplifier in the basic Distortion Reducer is $-S-S+S+D$. With a gain G_2 in the distortion channel this becomes $-S-G_2S+G_2S+G_2D$, which we may write as $-S(1+G_2)+G_2(S+D)$. The first term is the original signal multiplied by the gain of the equivalent pre-amplifier, and the second term is equivalent to that produced by a conventional negative feedback path.

I also offer the following more general treatment, in the hope that it may be productive and begin to answer Mr Cocking's call for a comparison of the two ways of reducing distortion.

Let the main amplifier have a (complex) gain $-G$, the term D now being reserved for distortion other than a mere quadrature term, let the attenuation at the output (previously $1/G$) be A, and let the distortion channel have a (real) gain G_2, as before. Writing x for the net input to the main amplifier, following the signal round the loop, and solving for x, we find

$$x = -\frac{S(1+G_2)+D}{1+G_2AG} \qquad (1)$$

If G is real (no phase shift in the main amplifier) and A is made equal to $1/G$ as before, this reduces to

$$x = -S - \frac{D}{1+G_2}$$

confirming the earlier result that the equivalent distortion input D is effectively reduced by a factor $(1+G_2)$.

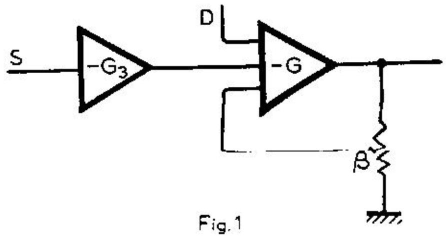


Fig. 1

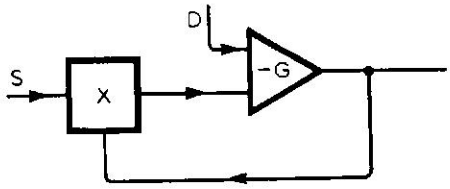


Fig. 2

Now consider the conventional circuit shown in Fig. 1. A similar analysis leads to

$$x = -\frac{G_3S+D}{1+G\beta}$$

If β is chosen to be equal to G_2A, and G_3 to be equal to $(1+G_2)$, this becomes identical to eqn. (1), showing that the two feedback systems are equivalent, even when there is a phase shift in the main amplifier, and that stability should be as good, or as bad, with either system. The relative merits of the two systems may turn out to depend on subtle considerations of linearity in the op-amps, interference with the input circuit of the main amplifier, or the like.

Finally, I offer Fig. 2 for consideration. X is a linear active network. It will be seen that the Distortion Reducer, the conventional circuit, and others as yet unconsidered can all be drawn in this form. One would expect them all to behave similarly.

Richard G. Mellish,
Watford,
Herts.

Quantity names

Since the discussion on my "Unified Dimensional Display" (March 1972), was published in the January 1973 issue, the dimensional position occupied by "magnetic vector potential" has been allotted the name "fluxivity" by John G. McKnight in a project note on test tapes appearing in the *Journal of the Audio Engineering Society* for March 1973. This is in order to describe the quantity "tape flux per unit track width" used in magnetic recording, measured basically in Wb/m, but conveniently referred to nWb/m in actual practice.

In view of this tendency to evolve new quantity names when needed, I suggest the replacement of "1/permittivity", or "reciprocal permittivity", (unit m/F), in my display system by the quantity "forbidivity" (or "forbiddivity"), forbid being an antonym of permit — or can readers suggest something better?

R. N. Baldock,
Harrow,
Middlesex.