Current dumping audio amplifier

Output power transistors' non-linearity does not appear in amplifier transfer characteristic

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If Harold Black did not actually invent negative feedback, he was certainly the first to show a comprehensive understanding of the subject in his famous patent of 1937. Nine years earlier he took out a patent on feed-forward error correction[1]. Relatively small variations on this nearly 50 year old concept have led to the development of a new type of audio output circuit with attractive properties. The circuit was the subject of a paper presented to the 50th convention of the A.E.S. by M. P. Albinson and the writer earlier this year.

An audio power amplifier is required to produce an output signal that differs from the input signal in magnitude only. It must therefore have occurred to every circuit designer that it should be a simple matter to take a portion of the output, compare it with the input to derive an error signal. It is then only necessary to amplify this error signal and add it to the output in the correct amplitude and phase to cancel completely the distortion of the primary amplifier. Of course, one is left with distortion of the error amplifier but being of very low power this can be made negligibly small without much difficulty.

There is a special appeal in feed forward error correction for transistor power circuits. Because of thermal limitations, the output transistors in the majority of audio amplifiers operate in class B, in which alternate output transistors handle the negative and positive signal excursions. The output transistors are carefully biased to obtain a reasonably smooth transition from one to the other. If the bias is insufficient there will be a discontinuity in the transfer characteristic. If the bias is too great, there will be a region of overlap when the mutual conductance will be doubled. The curvature of the characteristic near cut-off precludes there being a perfect bias condition and this is further aggravated by the fact that the junction temperature and hence the bias is a varying factor depending upon both the long term and immediate past history of the programme dynamics. A compromise is
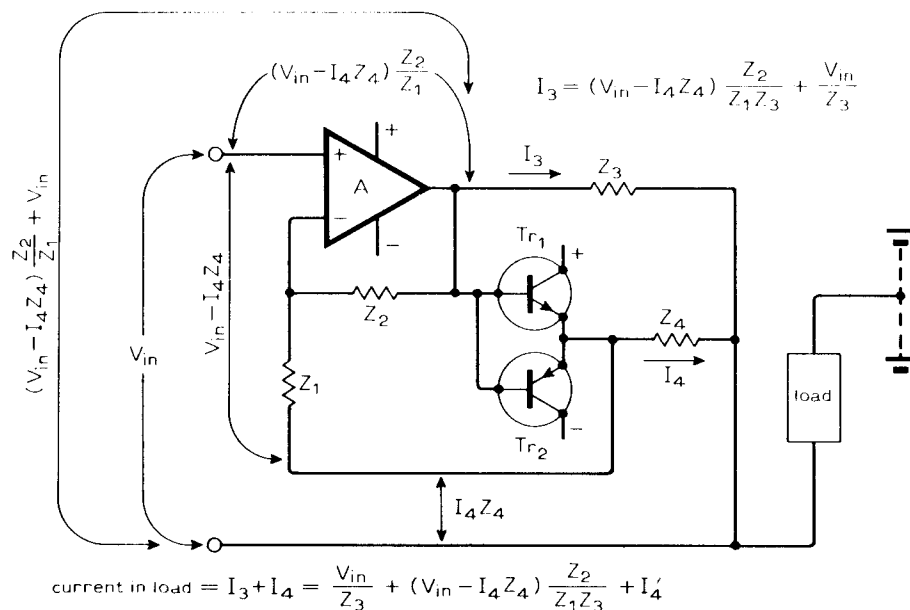
selected and overall feedback is applied to obtain an acceptably linear characteristic. Excellent amplifiers have been produced along these lines. Nevertheless, whereas feedback reduces distortion to a small and no doubt negligible amount, feed-forward carries the promise of reducing to zero the distortion of that part of the amplifier over which it is applied. If this is the class B stage, then not only does the distortion itself disappear but all the paraphernalia of quiescent current adjustment and thermal tracking disappears with it.

Feed-forward has only really flourished in areas where stability problems prohibit the use of feedback[2]. In the field of domestic audio amplifiers, it has failed to fire the imagination of all but a few[3]; presumably due to the extra complications and the undoubted practical problems of adding the error channel to the main 'stiff' output in an elegant manner.

If feed-forward is applied within the loop of a feedback amplifier, its stability advantage is necessarily forfeit. Nevertheless, in return, the need for a separate error amplifier can disappear and mutual loading problems disappear with it. A circuit developed on these lines carries an error component bypassing the main output transistors and so largely releasing them of linearity requirements. This technique has become known as 'current dumping' since this is descriptive of the rather mundane functions they are called upon to perform.

The basis of the new approach is shown in Fig. 1. Amplifier A is a small class A amplifier capable of providing the total required output voltage swing but with limited output current capability. Tr_1 and Tr_2 are current dumping transistors which supply the major part of the load current.

Fig. 1. Basic circuit parameters.

$$I_3 = (V_{in} - I_4 Z_4)\frac{Z_2}{Z_1 Z_3} + \frac{V_{in}}{Z_3}$$

$$\text{current in load} = I_3 + I_4 = \frac{V_{in}}{Z_3} + (V_{in} - I_4 Z_4)\frac{Z_2}{Z_1 Z_3} + I_4'$$

It will help in visualising the operation if the impedances are assumed to be resistors of values $Z_1 = 1k$ ohm; $Z_2 = 100k$ ohm; $Z_3 = 100$ ohm; and $Z_4 = 1$ ohm. In the interest of simplicity we have assumed Z_4 to be negligibly small compared to Z_1, and for the time being we will assume that the voltage output of amplifier A is completely defined by the external impedances.

With Tr_1 and Tr_2 turned off, amplifier A will deliver current to the load via Z_3. The current with the values suggested will be 1.01 amps/volt because the second term in the brackets is zero (no I_4 current from the dumpers). When half a volt or thereabouts appears across Z_3, one or other of the dumpers Tr_1 or Tr_2 will begin to turn on and pass some current I_4 into the load. We have selected resistor values such that Z_4Z_2/Z_1Z_3 is unity so that the second term in the expression for the I_3 current is exactly equal and opposite to I_4 (this second term is the feed-forward error correction component). Currents I_3 and I_4 add in the load so that no matter what the magnitude of I_4, the overall mutual conductance remains constant. We can say that any distortion in Tr_1 and Tr_2 produces perturbations in the current I_4 and since this causes exactly equal and opposite perturbations in I_3, no distortion appears in the load.

Tr_1 and Tr_2 have only one function to perform and that is to dump current into the load sufficiently accurately and sufficiently fast to come to the rescue of the class A amplifier and prevent it from overloading. If this is achieved then the class A amplifier, although it may have considerable gymnastics to perform, will be in complete control of the load current at all times.

Fig. 1 does not look like a practical hi-fi amplifier since its output is constant current and the input is floating relative to the power supply. Nevertheless it is obvious that if the input is returned to the other end of the load all the unique properties of Fig. 1 will still apply though perhaps a little less simple to visualise. This done, we have an amplifier whose output source impedance is Z_4 and Z_3 in parallel.

Two further changes are desirable. A practical amplifier is required to have an internal impedance small compared to the load at audio frequencies and stability requires that the internal loop gain falls with frequency. Both these conditions are met by the use of an inductor for Z_4, a capacitor for Z_2 and resistors for Z_1 and Z_3. The requirement for zero distortion from the dumpers is that Z_4Z_2/Z_1Z_3 is unity at all frequencies of interest. This is achieved if $L = RRC$. Fig. 2 shows the circuit with the modifications carried out. (In order to keep the system operating at all frequencies it is necessary for a resistor in series with the inductor to have a conjugate match with a parallel resistor across the capacitor. This has been omitted for simplicity.)

Fig. 2 begins to look very familiar, in fact just like a conventional amplifier with the biasing removed and a small inductor added. Is this really all that is necessary to produce the perfect amplifier? The answer, of course, is no, not quite; the circuit is over-simplified. We have pushed all the problems back into the class A stage and whilst the distortion would indeed be zero if the class A stage were perfect, this cannot be completely so in practice. We assumed in our analysis that amplifier A was completely controlled by the external impedances, that it had a perfect virtual earth at its input which implied perfect regulation at its output. The effect of departure from this ideal can be assessed by calculation from a deliberate unbalance of the four component bridge, whether this is due to tolerances of any of the components or to inadequate 'stiffness' at the output of amplifier A. With the values shown in Fig. 2, a 5% error in any component value will produce maximum intermodulation products of around 5μV at 1kHz; maximum possible i.m. of 0.01%, the maximum absolute level of these components being some 140dB below full power. Although frequency dependent, it is clear that balance is by no means critical and standard tolerance fixed components can be used without adjusting facilities.

We have said that the dumpers have
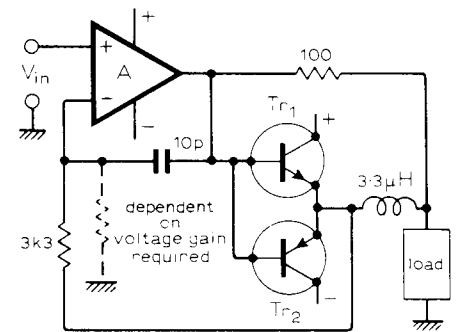

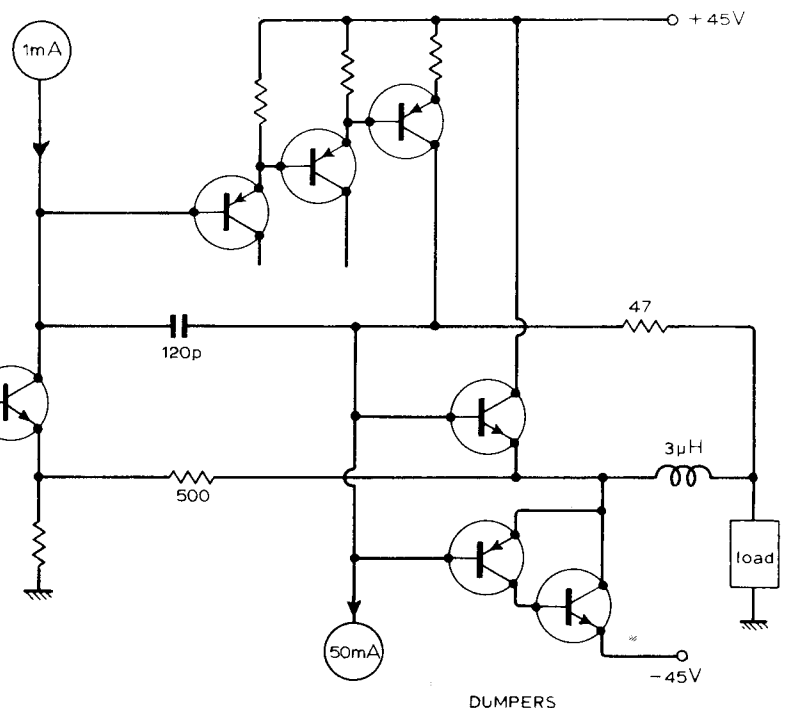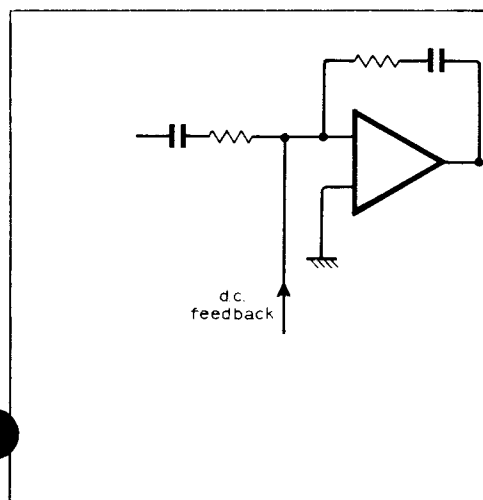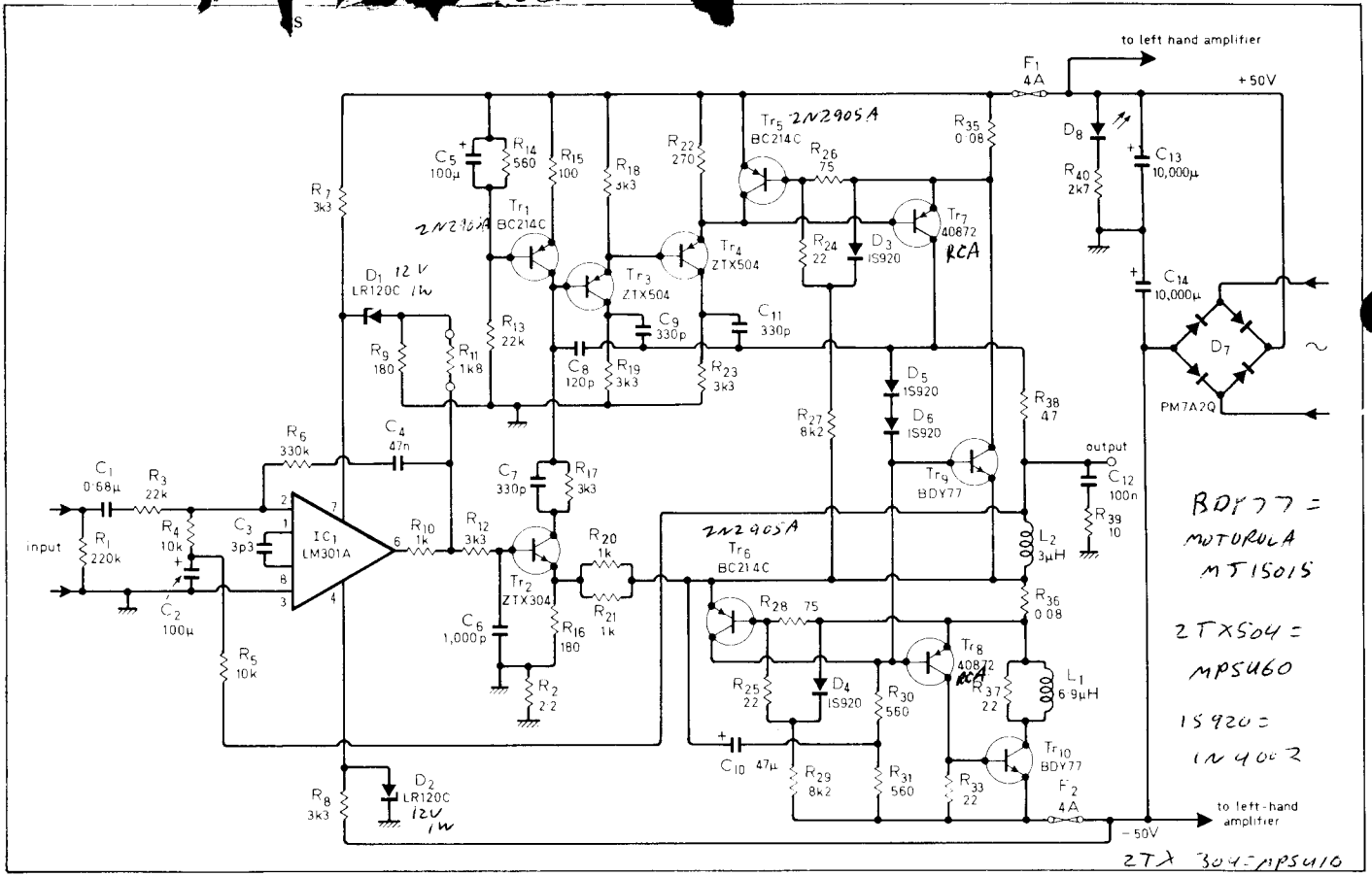Fig. 2. Basic diagram of principal elements.

Fig. 3. Simplified diagram showing Class A stage, current dumpers and bridge components.

Fig. 4. Full circuit diagram. Resistor R_2 is a protective connection provided to ensure earth continuity in the event that Tr_2 and its associated component panel are disconnected from the common earth chassis.

Fig. 5. The Quad 405, a commercial realization of the circuit design.

to be sufficiently fast to come to the rescue of the class A amplifier to prevent its overloading. Clearly they must be sufficiently fast to achieve this over the audio spectrum of the programme. There is, however, nothing whatever to say that they must do so at frequencies outside the audio range provided that steps are taken in the design of the whole amplifier to ensure that any such frequencies that may be present do not embarrass the amplifier performance within the audio range. If the system is properly designed it is possible to use relatively slow devices – inherently more rugged than fast devices – and to show in theory and

practice that they will never fail to come to the rescue of the low powered amplifier on any programme. If, however, the criteria are thought to be response to step functions, square waves and other factors not relevant to programme, then of course faster dumpers must be used commensurate with the rise times involved.

Fig. 4 shows a commercial amplifier circuit (the Quad 405) developed along these lines, Fig. 3 being a simplified diagram to indicate the relevant areas. The class A amplifier serves also as the driver for the top dumper. To counter this extra burden, the class A amplifier is a triple to give a very effective virtual earth. The mid frequency distortion of this amplifier measures about 0.005%, a region where slight component non-linearities etc. tend to deprive such measurements of any true meaning.

An extremely attractive feature of the technique is the complete absence of adjustments or alignment requirements and no thermal problems. Nothing to set up in manufacture and nothing to go out of adjustment during life. One may expect that after several years there will be far less variation, set to set, than is presently realised with most conventional circuits.

References
1. Black. US Pat. 1,686,792. 9th Oct. 1929.
2. Feedforward error control. Wireless World, May 1972, p.232.
3. Sandman, A. M. Reducing amplifier distortion. Wireless World October 1974, pp.367-371.
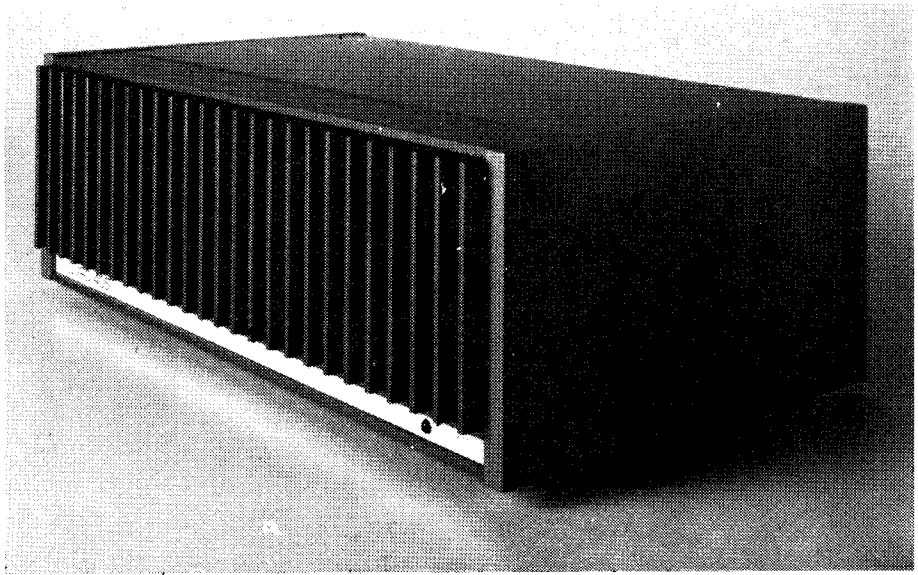
Packing

The amplifier is supplied with an input lead, mains connector, two voltage limiting resistors, and a spare mains fuse. The packing material comprises a two part expanded polystyrene shell and a cardboard carton and should be retained for re-use in case the unit has to be returned at any time.

Service

If servicing is required the amplifier may be returned to The Acoustical Manufacturing Co. Ltd., in Huntingdon, or to the agent for the country of purchase, without prior notification. A brief note giving details of any symptoms and the address for return of the unit should be enclosed with the amplifier.

Guarantee

This amplifier is guaranteed against any defect in material and workmanship for a period of twelve months from the date of purchase.

Within this period we undertake to supply replacement parts free of charge provided that failure was not occasioned by misuse, accident or negligence.
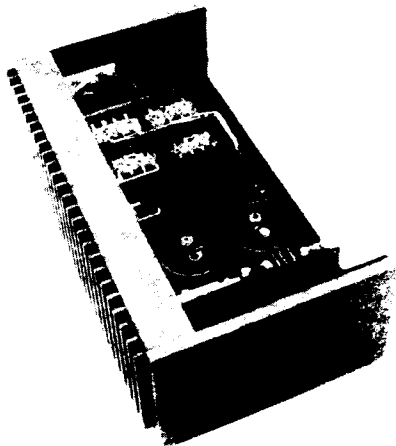
Description

The Quad 405 is a two channel power amplifier primarily intended for use in high quality sound reproducing systems. The amplifier is usually used with the Quad 33 control unit though other signal sources can readily be accommodated.

The amplifier uses a current dumping output circuit, a Quad invention which eliminates many of the problems associated with transistor amplifiers.

In a current dumping amplifier there is in effect both a low powered very high quality amplifier and a high powered heavy duty amplifier. The low power amplifier controls the loudspeakers at all times, calling upon the high power section to provide most of the muscle. The small amplifier is so arranged – it carries an error signal – that provided the larger power transistors (the dumpers) get within the target area of the required output current it will fill in the remainder accurately and completely. The reproduced quality is *solely* dependent on the small amplifier which because of its low power can be made very good indeed.

Problems of crossover, crossover distortion, quiescent current adjustment, thermal tracking, transistor matching, all disappear. There are no internal adjustments or alignments and the choice of power transistor types is less restrictive.

SIMPLIFIED SCHEMATIC OF 405 AMPLIFIER SHOWING CLASS A, DUMPERS & BRIDGE COMPONENTS
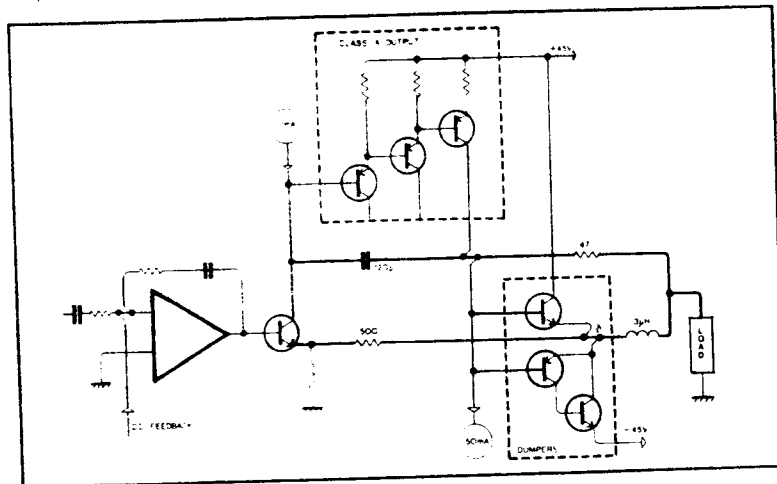
QUAD 405 SPECIFICATION

Measurements apply to either channel, with or without the other channel operating

Power Output

The amplifier is intended for use with loudspeakers of 4–16 Ω nominal impedance.

Power and distortion for various frequencies.
Continuous sine wave into 8 Ω resistive load.

    100 Hz any level up to 100 watts <0.01% D tot
    1000 Hz any level up to 100 watts <0.01% D tot
10,000 Hz any level up to 100 watts <0.05% D tot

For other impedances and frequencies see graphs.

Notes:
1. In addition to the performance into a resistive load R, the amplifier will maintain full voltage within the same distortion rating into a load R ± jX where X is any value from zero to infinity.
2. With the additional power limiter inserted the maximum output voltage is limited to 20V rms ± 10% (50 watts 8 Ω); all other performance figures unchanged.

Output Internal Impedance and Offset

3.3µH in series with 0.03 Ω
Offset <7mV.

Frequency Response

Ref. 1 kHz
Low frequency —1dB at 20 Hz. Filter attenuation as curve.
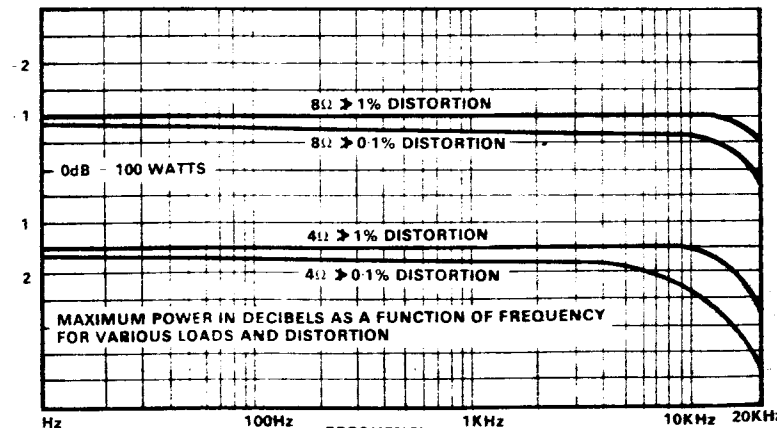High frequency 0.5dB 20 kHz –3dB 50 kHz.

Signal Input Level

0.5V rms ± 0.5dB for 100 watts into 8 Ω. Amplifier loads the input by 20k Ω in parallel with 220pF.

Signal Input Slew Rate Limit

0.1V/µS.

Provided the rate of change of input voltages does not exceed

total of all distortions appearing in the audio range (20–20,000 Hz) due to transient or repetitive waveforms with frequency components inside or outside the audio range will be at least 80dB below full rated power. If the major portion of the input energy is wanted signal then —80dB (0.01%) represents the maximum possible distortion on programme.

MAXIMUM OUTPUT POWER, OUTPUT VOLTAGE AND dB REFERRED TO 1 VOLT, AS A FUNCTION OF LOAD RESISTANCE. 1KHz ≯ 0.01% D$_{Tot}$.

MAXIMUM POWER IN DECIBELS AS A FUNCTION OF FREQUENCY FOR VARIOUS LOADS AND DISTORTION
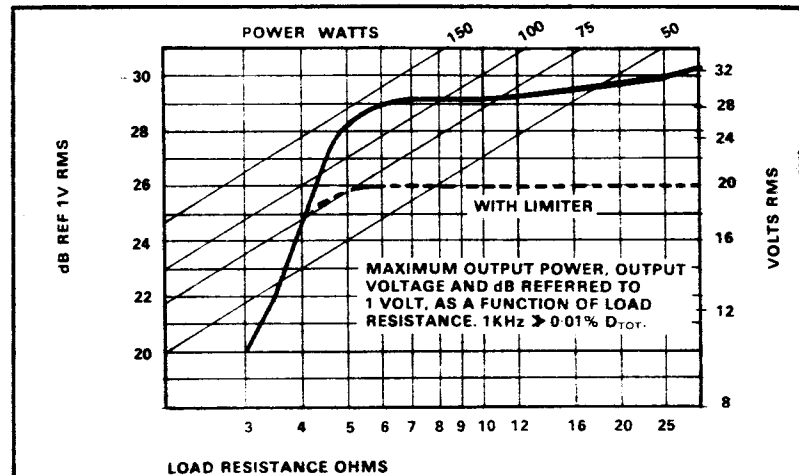
Signal Input Overload

Instantaneous recovery up to +20dB overload.

Crosstalk

(Input loaded by 1kΩ) 80dB @ 100 Hz
                        70dB @ 1 kHz
                        60dB @ 10 kHz.

## Hum and Noise

'A' weighted —95dB ref full power
Unweighted —90dB ref full power (15·7 kHz measurement
                        bandwidth).

Protection

The amplifier is suitable for use under the most arduous music
conditions and is electrically protected by current limiters;
7 amps in-phase current at peak voltage and $3\frac{1}{2}$ amps at zero
voltage. Shorting both outputs simultaneously on signal for an
extended period (minutes) is not protected.

Stability

Unconditionally stable with any load and any signal.

LOW FREQUENCY INPUT FILTER RESPONSE
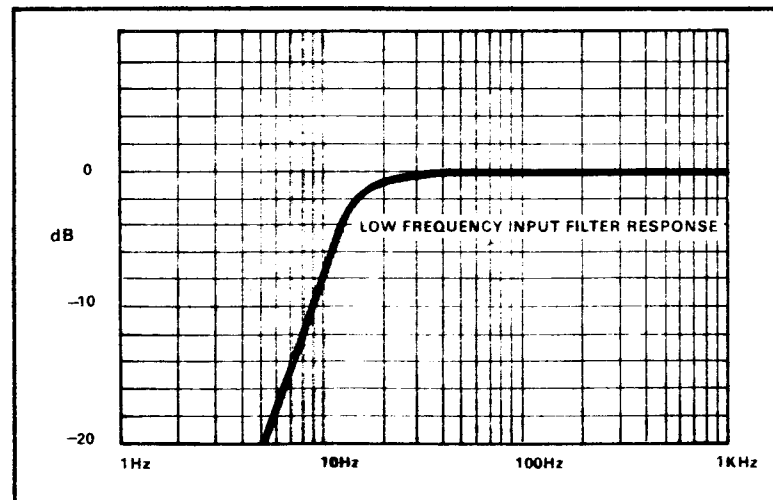
Power Input

110–120–130V, 220–230–240V
50–60 Hz, 30–350 watts depending on signal level.

Dimensions

Height   115 mm   (4·5")
Width   340·5 mm (13·4")
Depth   195 mm   (7·7")   allow an extra 38 mm (1·5") for
                             plug and socket.

Weight

9 Kg. (20 lbs.)

INSTALLATION

The Quad 405 carries no controls and may be mounted out of
sight in a cabinet or any other convenient location.

The Quad 405 is provided with a substantial heat sink, and
must always be adequately ventilated, particularly if positioned
in a cabinet or cupboard.

If used in close proximity to the control unit, tuner or magnetic
cartridge, care should be taken to ensure that hum is not
induced by radiation from the mains transformer of the 405.

Mains Supply

A mains voltage selector is fitted on the rear panel of the
amplifier (except for CSA units), which has six positions and
must be adjusted before the amplifier is connected to the mains
supply. The operating voltage is indicated by the arrow-head
above the voltage selector, the voltage selector being rotated to
the required voltage.

Earthing (Grounding)

The supplied mains connector is terminated at one end by a
two-pin plug. When the Quad 405 is used with a Quad 33
control unit, which should itself be earthed, the 405 will be
earthed via the audio lead and should not be connected to the
earth lead in the mains cable. In other cases, where the 405
must be earthed directly, a three-core mains lead should be used.

Input Level Control

When the Quad 405 is to be driven from an unbalanced or floating $600\,\Omega$ line, the circuit shown in Fig. (ii) should be used.
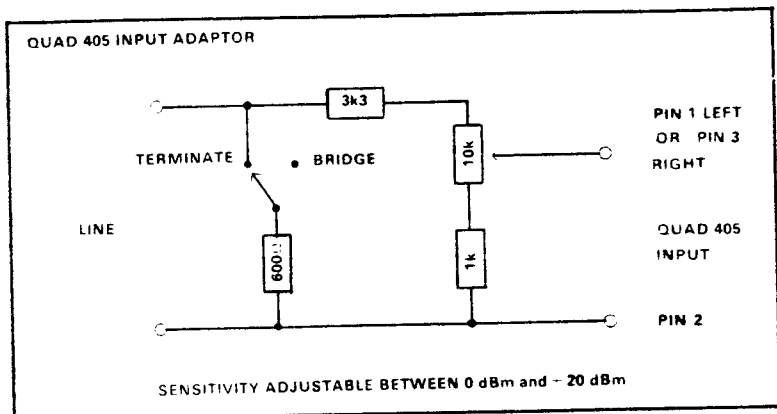

Fig. ii

Additional Loudspeakers

Fig. (iii) shows the switching arrangements if more than one pair of loudspeakers is to be used. The switch may be either of the rotary type or one of the proprietary switch boxes which are readily available.
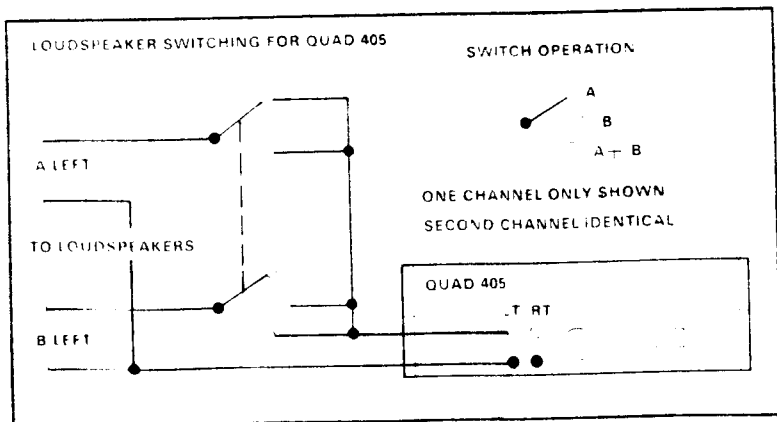

Fig. iii

Fuses

In addition to the mains supply fuse on the rear panel of the amplifier, each channel is protected by two internal fuses, located on the printed circuit boards.

The main fuse is a 2·5 amp surge-resisting (2·5AT) type for 200–250 volt supplies while a 5 amp surge-resisting (5AT) fuse is required when operating with 100–125 volt supplies. In either case all four internal fuses are 4 amp quick blowing (4AF). To reach the internal fuses it is necessary to remove the top cover of the amplifier, by undoing the two retaining screws and sliding the cover about 10 mm, (0·5"), backwards before lifting it clear. Withdraw the mains plug before removing the cover.

The indicator lamp on the amplifier is powered from the +50 volt supply. If the indicator lamp is on, the main fuse must be intact, but illumination of the indicator lamp does not imply that the internal fuses are intact.

When the mains supply is drawn from the Quad 33 or similar fused source, the current rating of the source fuse should be the same as that of the main fuse of the 405. See above. The spare fuse packed with the amplifier may be used.

Note : Existing Quad 33 s are fitted with 2AT fuses in 240V models and 4AT fuses in 110V models.

Input Connections

The input lead supplied with the Quad 405 should be used with signal sources other than the Quad 33. The phono plugs are marked L and R and should be connected to the appropriate output sockets of the pre-amplifier or mixer.

When used with the Quad 33 control unit, the standard four-pin Din/four-pin Din lead supplied with the 33 should be used.

For remote installation up to 30 metres of screened lead of 60pF/metre maximum capacity may be used.

Loudspeaker Connections

The Quad 405 is provided with spring loaded speaker terminals. 24/0·2 mm flex with a rating of 6 amps, or similar, should be used to connect the loudspeaker to the amplifier. For very short runs, up to five metres, 16/0·2 mm flex is permissible.

Each loudspeaker should be connected to its appropriate amplifier output so that the two pairs of wires are connected in the same way, to ensure that the speakers operate in phase. The output terminals are colour-coded to facilitate this.

Should there be any doubt the phasing can be checked later experimentally. (See Page 11.) Where one loudspeaker only is used for mono, either channel may be used and the terminals of the other channel left vacant. A dummy load resistor is not required.

In cases where loudspeakers, such as the electrostatic loudspeaker, also require an energising supply, the instructions provided with the loudspeaker should be followed.

Each loudspeaker should be capable of handling the full output of the amplifier, or the protection facility described below should be used.

The red output terminals must not be connected in parallel.

Loudspeaker Protection

The loudspeaker manufacturer usually states a maximum recommended amplifier power for his loudspeaker. If this figure is below 100W (into 8Ω) then the limiter facilities provided with the amplifier should be fitted. Failure to do so may cause damage to the loudspeaker and infringe its guarantee.

Maximum safe power for most loudspeakers is time and frequency dependent and so is difficult to define precisely for a music signal. Some manufacturers will permit their loudspeakers to be used with amplifiers exceeding the quoted handling capacity provided certain precautions are observed. This can sometimes be advantageous in enabling short duration high level peaks to be handled without overload. The advice of the loudspeaker manufacturer or his agent should always be obtained before embarking on such a procedure.

Voltage Limiting

To limit the voltage of the Quad 405 to 20V rms, the cover should be removed by undoing the two retaining screws and sliding the cover about 10 mm, (0.5"), backwards before lifting it clear and the two 1.8kΩ resistors provided should be inserted in the sockets marked R11. (See illustration.) The sockets are spring loaded (see diagram), and the resistor should not be soldered. Withdraw the mains plug before removing the cover.
An adhesive label is provided to show that the limiters are in position.
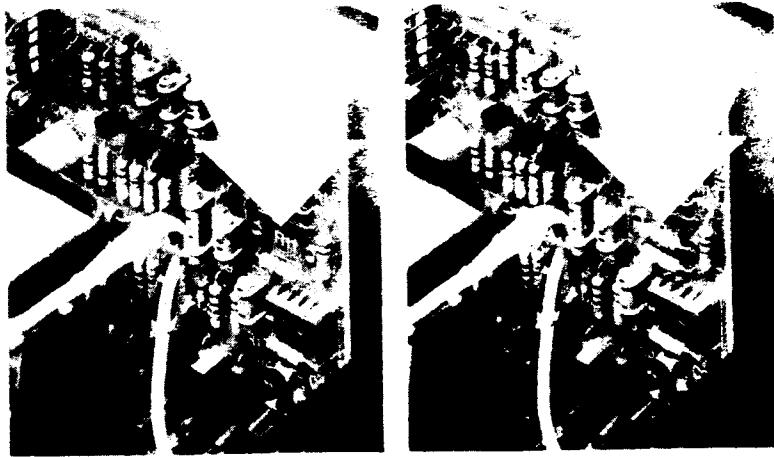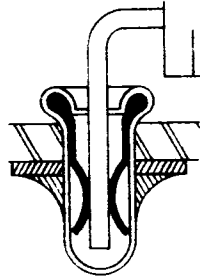
Quad Electrostatic Loudspeaker

The Quad 405 amplifier should always have the voltage limiters in place when driving the Quad electrostatic loudspeaker.
Failure to observe this precaution will result in inevitable damage to the loudspeaker.
Note:
Quad electrostatic loudspeakers prior to serial number 16800 (March 1966) need slight modification before being used with the Quad 405 unless they have already been modified for use with the Quad 303.

Loudspeaker Phasing

If there is any doubt about the way in which the loudspeakers are connected (see Page 9), their phasing may now be checked by playing a mono disc over both channels, when the sound should appear to emanate from a point midway between them. If this is indefinite the connections to either of the loudspeakers, but not both, should be reversed. Correctly connected the loudspeakers will give a definite centre sound source accompanied by a more full-bodied sound in the tenor and bass registers.

Headphones

Headphones should be connected to the Quad 405 outputs in place of the loudspeakers and a typical wiring arrangement is shown in Fig. i. Any of the headphone switch units on the market will provide the necessary switching and many of them also provide for incorporating the resistors which adjust the signal level to suit most magnetic headphones. The Quad 405 does not require dummy load resistors.

Electrostatic or other types requiring a high level input should be connected in accordance with manufacturers' instructions.

The loudspeaker return leads (which may be commoned if necessary) must be taken to the black sockets and never to chassis or earth.

Fig. i
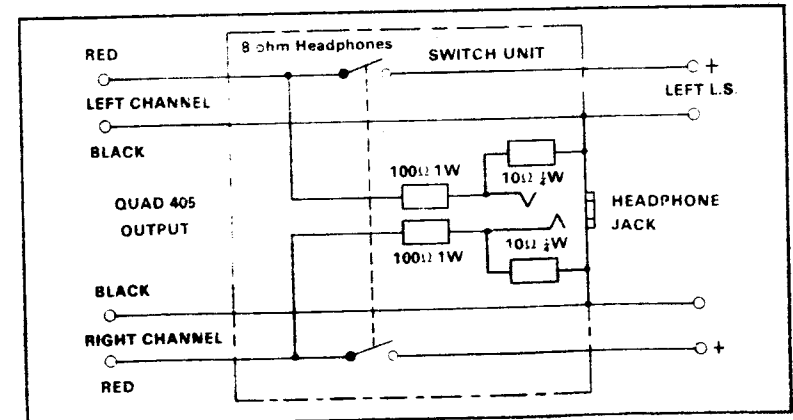
CURRENT DUMPING AUDIO AMPLIFIER

I have had many enjoyable discussions with P. J. Walker, M. P. Albinson, P. Blomley and R. C. Bowes in the quest for the ideal audio amplifier which would be totally free from audible distortion, have no adjustments of any kind, and be economical and straightforward to manufacture. Numerous fascinating schemes have been considered, and assessing their overall relative virtues has been quite difficult — and indeed, at times, very perplexing.

When the Quad 303 circuit was first evolved, it was evident that the very good linearity of the individual triples, resulting from their internal feedback, was, in a sense, being partially wasted, because the existence of some residual crossover distortion in the transfer of current from one triple to the other necessitated a large amount of overall feedback in addition. A superb performance is, of course, thus obtained, but one was left feeling that if only a circuit could be devised that would sense when both triples were on

together and apply extra negative feedback to prevent the gain from increasing, then a more economical design, preferably free from preset adjustments, might be possible. Countless hours were spent scratching around trying to solve this and related problems, and there were moments of elation when it was thought that an answer had been found. But then it turned out that the proposed solution, to work ideally, involved the concept of infinite loop gain – camouflaged, maybe, as a requirement for a zero source impedance at some internal point in the circuit. In other words it turned out merely to be an example of Mr Halliday's "familiar assertion that the distortion can be made negligible by huge amounts of feedback".

Then Peter Blomley's fundamental and excellent new idea came along[1] – a class B amplifier in which both halves of the output stage retained their full mutual conductance throughout the whole audio cycle. This seemed to me at first to be the total answer to the problem of an adjustment-free amplifier with first-class performance, and I did a good deal of very encouraging experimental work leading to simplified circuit designs. It became evident, however, that though the technique is basically absolutely sound, the major practical problem is to ensure that, in the absence of any kind of adjustments or selection of transistors, the quiescent current will fall within reasonable practical limits, albeit quite uncritical ones, without wasting too much output power in highish-valued output-stage emitter resistors, or requiring, somewhere in the circuit, transistors having closely-matched V_{be} values at a given current. Circuits using dual transistors, or i.cs, in the quiescent-current-determining circuitry, were inclined to become undesirably complex, though excellent results were obtainable.

I tried to persuade Peter Walker, at an early stage, that Quad would do well to develop an amplifier based on the Blomley idea, but he and Michael Albinson, with remarkable intuitive wisdom, sensed that the economics of such an approach might well be less than ideal, and they continued to investigate other techniques. The current-dumping scheme as conceived and developed by them seems to me to have an impressive elegance and economic "rightness" about it. Much of the practical success of the 405 design is due to the master-stroke of making the class A amplifier into an integrator, with an inductor elsewhere in the circuit, but there is also the ingenious economy of making the integrator output transistor (Tr_7 in Fig. 4, page 562, December 1975 issue) function in addition as the driver for one of the dumper transistors. (For practical reasons the dumpers-off regime is displaced to one side of the zero-load-current state.)

For the record, it may be mentioned that R. C. Bowes independently put forward a proposal for a current-dumping amplifier circuit, in which the current fed by the dumpers to the load was monitored not by a resistor directly in series with the load, but by small resistors in the collector leads of the dumpers. A negative-feedback voltage was derived from the sum of the voltage drops across these resistors, and values were so chosen that the gain of the system was independent of whether or not the dumpers were in action. So far as I can recollect, however, nothing comparable with the integrator-and-inductor scheme was envisaged.

Having just completed a chapter on amplifiers for the forthcoming Butterworths

publication "Radio, TV and Audio Technical Reference Book", I thought some *Wireless World* readers might be interested in the simple explanation there given of the Quad current-dumping technique. It seems to me that this rather different approach has the virtues (a) that it is more directly related to very familiar ideas and (b) that it provides a simple and convincing physical argument that the scheme must work, without recourse to any algebra. I believe that it is always very much worthwhile to seek the simplest possible, sound, non-mathematical explanation of any circuit, to supplement the algebraic analysis which may already have been done.

Consider first diagram (a). In the absence of overall feedback via R_1, and assuming for convenience a resistive load, the transfer characteristic will be as at (b), giving gross distortion. With overall feedback, the transfer characteristic is much better, as shown at (c); but however much feedback is applied, it can never be quite perfect. Clearly what is wanted is to apply a little more negative feedback in the AB and A'B' regimes than in the AA' regime, thus equalizing the slopes in the three regimes. This is achieved with the (d) arrangement, in which R_1 receives a small extra voltage component (the voltage drop in R_4) only when the dumpers are in action. If R_4 is made too large, there will evidently be too much extra feedback, and the gain will then be *less* in the AB and A'B' regimes than in the AA' regime. The correct value of R_4 will thus give exactly

equal slopes, and there is clearly no need for infinite gain to exist anywhere in the circuit for this result to be obtained.

If R_2 is made very large, the system will have a large forward gain and there will then be a lot of overall feedback. Consequently, even with $R_4 = 0$, the characteristic shown at (c) will have nearly equal slope everywhere, so that a very small value of R_4 is all that is then required for perfect slope equalization. Thus, if R_2 is replaced by a capacitor, giving high forward gain at low frequencies only, the impedance element replacing R_4 needs to have an impedance which is very small at low frequencies but which increases in proportion to frequency to offset the effect of the falling forward gain introduced by C. An inductor is therefore required, as shown in (e).

When the circuit shown at (e) is handling a high-level sine-wave signal, the voltage waveform at 'P' is, of course, very non-sinusoidal, and it is therefore necessary for the class A integrating amplifier to have a clean performance up to much higher frequencies than the upper limit of the audio band. A very simple circuit is capable, however, of giving the required performance.

One way to arrive at the correct choice of values for distortionless results with circuit (e), assuming a perfect integrator, is as follows. Consider first the ideal limiting case that the dumper stage is not only on, but that it has infinite mutual conductance. Then the incremental output impedance of the complete circuit is clearly that of R_3 and L in

parallel, for at the left-hand side of both of these elements we see the zero output impedance of an ideal feedback circuit. Now consider the other limiting case, where the dumpers are completely off, and work out the output impedance (or, more conveniently, admittance) of the circuit which then applies. It will be found that if L is made equal to $R_1 R_3 C$, this output impedance is equal to that of L and R_3 in parallel, as before. Now any system with a distortionless no-load output voltage, and an output impedance independent of loading, must be distortionless.

P. J. Baxandall,
Malvern,
Worcs.

1. Blomley, P., "New Approach to Class B Amplifier Design", *Wireless World*, Feb. 1971, pp. 57-61 and March 1971, pp. 127-131. (Also in *Wireless World* "High-Fidelity Designs" book.)

In the April issue of *Wireless World*, Mr P. G. Walker tries to prove that the feed-forward is linear, referred to the input. It would then be possible for the A gain (or G_{m1}) to be arbitrarily low and the current dumping to be linear at the same time. This is not the case. The error in the top figure on p. 55 is that it does not show the interaction between G_{m1} and G_{m2}. If G_{m2} is nonlinear it is impossible for G_{m1} (or A) to have a linear voltage *and* current gain consistent with linear load current. During the cross-over instant, when the power-section is cut-off, the total gain is only $A \cdot R_L/(Z_3 + R)$. During the remainder of the cycle the gain is A, because the power-section has approximately unity voltage gain. This causes some cross-over distortion if the gain of A is not infinite. No

(a)

(resistive load assumed)
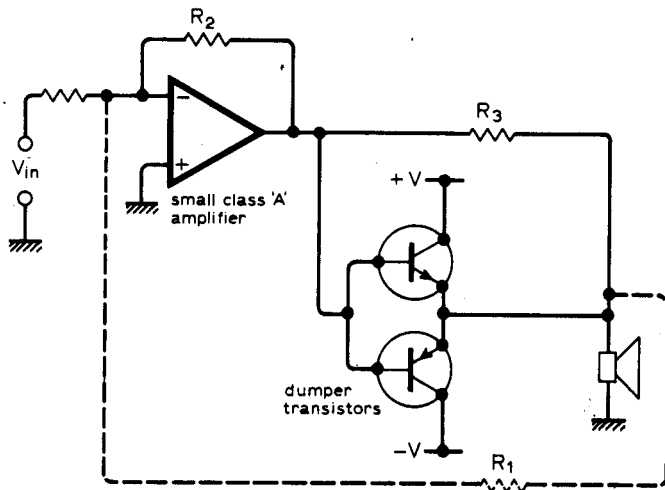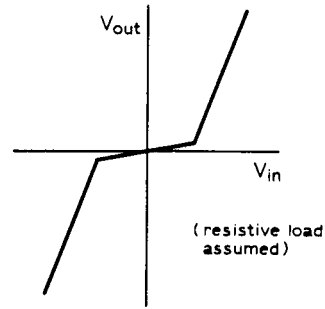
(b)
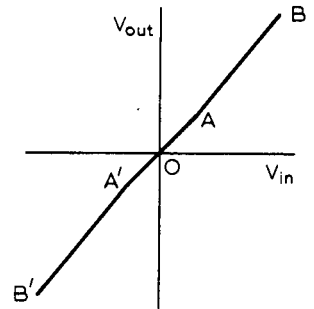
(c)

(d)

(e)

more proof is needed to show that the feed-forward is not linear, referred to the input terminals.

One may look a little closer at the non-linear feed-forward, or shall we say, non-linear *gain*, assuming the existence of one of the following extremes of A and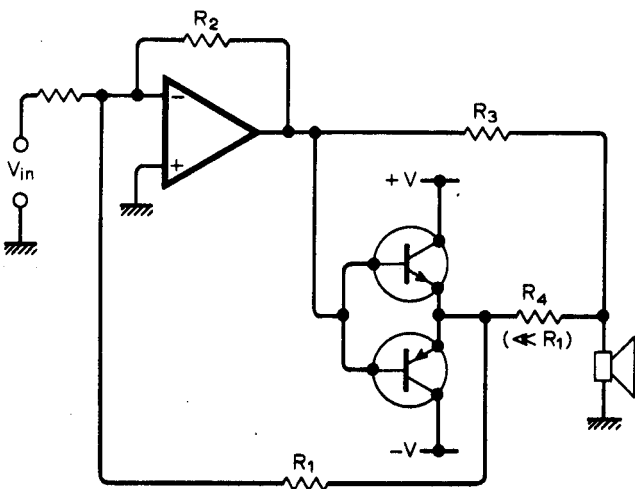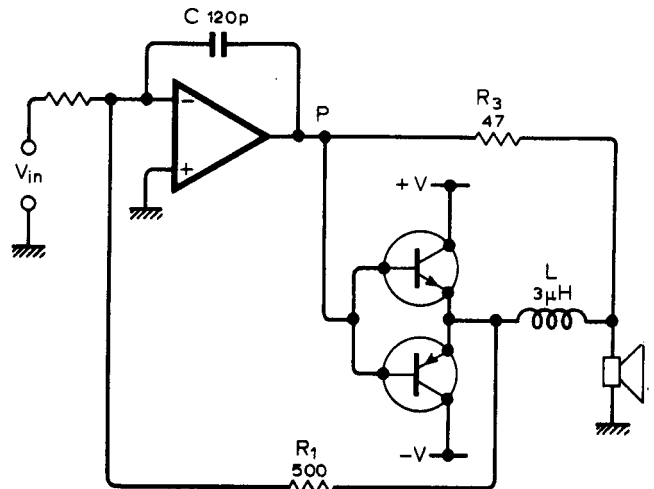 the power-section. Independent of how the amplifier A is fed back, it may have one of the extremes of voltage or current feedback or no feedback at all. Amplifier A may thus, by design, have a constant-voltage or constant-current output.

Constant-voltage output in series with Z_3 gives a constant G_{m1} — as long as Tr_1 and Tr_2 take no input current. But when they draw a base current comparable to the current in Z_3 the G_{m1} is no longer constant. Constant current generated by A has the same error. The conditions for constant G_{m1} do not exist as long as Z_3 is connected in parallel to the variable input impedance of Tr_1 and Tr_2. In other words there is no way to make A linear, which was required to make term I_3 disappear from the equations. Since there is no linear relationship between the output voltage and the output from amplifier A, the "rigidity of interconnection" is missing, as pointed out by Mr A. Sandman.

The current dumping method acquires a linear *feedback* current, i.e., it is proportional to the total output current, but this goal can with the same merit by arranged by common voltage feedback (assuming constant load) as shown by Mr J. G. Bennett. The feedback from each output path is made proportional to the output current in that path. This holds both statically (feedback resistors only) and dynamically (feedback resistors, capacitors and inductors are used) because of the design rules suggested by P. J. Walker:
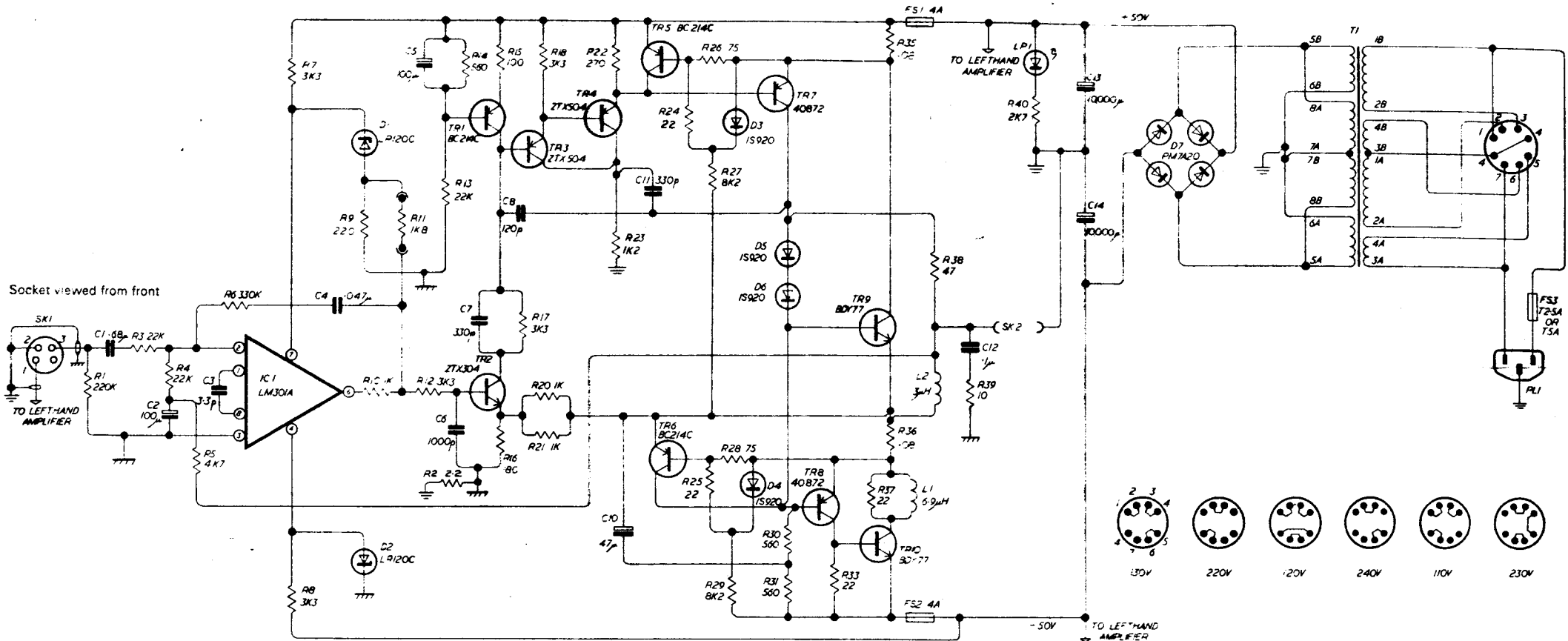
$$\frac{\text{feedback current}}{\text{output current}} = \frac{Z_3}{Z_2} = \frac{Z_4}{Z_1} = k.$$

That is: 1 mA of output current (or 1 mA/µs) causes $k \cdot 1$ mA feedback current, whether the current is sensed by Z_3 or Z_4. In addition, there is only one summing point. The audio amplifier can not sense from where the feedback signal originates — all the output current branches being equally weighted by the rule of design. The *forward* linearity will not be changed by the divided feedback loops, since the same input voltage differential V' is needed to drive the current I_3 and the base current of Tr_1 and Tr_2, *irrespective* of how the feedback is taken.

The current dumping method would be unique if the feedback network could separate the different output paths. But it cannot, and the mode of operation is not different from one feedback resistor sensing the output current or output voltage or parts of both. The use of reactances, as in Fig. 2 in Walker's first paper, causes the feedback to increase with the frequency in the same way as if the single feedback resistor is shunted by a small capacitor. There is one implicit feature — that of current continuity, accomplished by Z_3. If Z_3 has a low impedance, any non-linear amplifier would be less non-linear. The existence of Z_3 causes an improvement, but not a change of nature of the amplifier.

One arrives inevitably at the conclusion that the current-dumping scheme has the same forward nonlinearity and identical feedback collection of output current information, as an ordinary amplifier with zero bias current and with the same amount of feedback. In fact there is no difference at all.

Bengt G. Olsson,
Xelex AB,
Stockholm.

Socket viewed from front

TR5 BC214C
FS1 4A
+50V
TO LEFTHAND AMPLIFIER
LP1
T1

R7 3K3
R14 560
R15 100
R18 3K3
P22 270
R26 75
R35 .08
R40 2K7
C13 10000p

D1 LA120C
TR4 ZTX504
R24 22
TR7 40872
D3 1S920
D7 PM17A20

TR1 BC214C
TR3 ZTX504
R27 8K2
C11 330p
C14 10000p

R9 220
R11 1K8
R13 22K
C8 120p
R23 1K2
D5 1S920
R38 47

R6 330K
C4 .047
D6 1S920
TR9 BDY77

SK1
C1 .68
R3 22K
C7 330p
R17 3K3
SK2
C12 1µ
R39 10
L2 3µH

R1 220K
R4 22K
C3 33p
IC1 LM301A
R10 1K
R12 3K3
TR2 ZTX304
R20 1K
L1 6.9µH

C2 100µ
R5 4K7
C6 1000p
R16 8C
R21 1K
R36 .08
TR6 BC214C
R28 75

R2 2.2
R25 22
D4 1S920
TR8 40872
R37 22

D2 LA120C
C10 47µ
R30 560
TR10 BDY77

R8 3K3
R29 8K2
R31 560
R33 22
FS2 4A
−50V
TO LEFTHAND AMPLIFIER

FS3 T2.5A OR T5A
PL1

No	VALUE	TOL	REFERENCE	STOCK No
R1	220K	±10%	ISKRA UPM 050	187/C
R2	2.2	±5	MORGANITE TYPES	330A
R3	22K	±2%	ISKRA UPM 050	2"E
R4	22K	±2%	ISKRA UPM 050	2"E
R5	4.7K	±10%	ISKRA UPM 050	240/P
R6	330K	±5%	ISKRA UPM 050	179/C
R7	3K3	±10%	ISKRA UPM 050	244/B
R8	3K3	±10%	ISKRA UPM 050	244/B
R9	220	±5%	ISKRA UPM 050	225/A
R10	1K	±2%	ISKRA UPM 050	256/A
R11	1K8	±10%	ISKRA UPM 050	253/B
R12	3K3	±10%	ISKRA UPM 050	244/B
R13	22K	±2%	ISKRA UPM 050	27/E
R14	560	±10%	ISKRA UPM 050	245/A
R15	100	±10%	ISKRA UPM 050	305/P
R16	180	±2%	ISKRA UPM 050	290/B
R17	3K3	±10%	ISKRA UPM 050	244/B
R18	3K3	±10%	ISKRA UPM 050	244/B
R19				
R20	1K	±2%	ISKRA UPM 050	256/A
R21	1K	±2%	ISKRA UPM 050	256/A
R22	270	±10%	ISKRA UPM 050	283/A
R23	1K2	±10%	MULLARD PR37	
R24	22	±10%	ISKRA UPM 050	37/B
R25	22	±10%	ISKRA UPM 050	37/B
R26	75	±5%	ISKRA UPM 050	356/C
R27	8K2	±5%	ISKRA UPM 050	238/B
R28	75	±5%	ISKRA UPM 050	356/C
R29	8K2	±5%	ISKRA UPM 050	232/B
R30	560	±10%	ERIE 7005-510 OR MULLARD PR52	
R31	560	±10%	ERIE 7005-510 OR MULLARD PR52	
R33	22	±10%	ISKRA UPM 050	37/B
R35	0.8		ACOUSTICAL DRG A4/12303	

No	VALUE	TOL	REFERENCE	STOCK No
R35	0.8		ACOUSTICAL DRG A4/12303	
R37	22	±10%	ISKRA UPM 050	37/B
R38	47	±5%	ISKRA UPM 050	30/D
R39	10	±10%	ISKRA UPM 050	320/D
R40	2K7		MULLARD PR37	
C1	.68µ		SIEMENS 100V B32541	488/C
C2	100µ	±10%	UNION CARBIDE 3V E100E3	
C3	33p	±20%	STABILITY 38P	
C4	.047µ		SIEMENS 250V B32541	509/H
C5	100µ		ERO 6V EK	455/B
C6	1000p		ERO 400V KT-190-210-4	
C7	330p	±20%	STABILITY 38P H-K	
C8	120p	±5%	STABILITY 38P 42200	
C9				
C10	47µ		ERO 40V EK	460/C
C11	330p		STABILITY 38P	
C12	1µ		SIEMENS 250V B32541	495/J
C13	10,000µ		ERIE 63V 32110-102-0103-OT-0630	
C14	10,000µ		ERIE 63V 32110-102-0103-OT-0630	
D1			AEI LA120C	
D2			AEI LA120C	
D3			TEXAS INSTRUMENTS 1S920	
D4			TEXAS INSTRUMENTS 1S920	
D5			TEXAS INSTRUMENTS 1S920	
D6			TEXAS INSTRUMENTS 1S920	
D7			AEI PM17A2Q	
IC1			LM301A	

No	VALUE	TOL	REFERENCE	STOCK No
TR1			BC214C OR BCX36	
TR2			BC682 OR ZTX304 OR BCX32	
TR3			E5458 OR ZTX504 OR BCX36	
TR4			E5458 OR ZTX504 OR BCX36	
TR5			BC214C OR BCA36	
TR6			BC214C OR BCX36	
TR7			40872 OR 2SA740	
TR8			40872 OR 2SA740	
TR9			2N3773 OR BDY77	
TR10			2N3773 OR BDY77	
FS1	4A			
FS2	4A			
FS3	T2.5A		220-240V	
	T5A		110-130V	
LP1			HEWLETT-PACKARD 5082-4850 RED	
			ACOUSTICAL DRG A3/12362	

No	VALUE	TOL	REFERENCE	STOCK No
L1	6.9µH	±20%	ANCO TC1/65	440/B
L2	3µH	±5%	ANCO 440/D	440/D

110V   220V   120V   240V   110V   230V
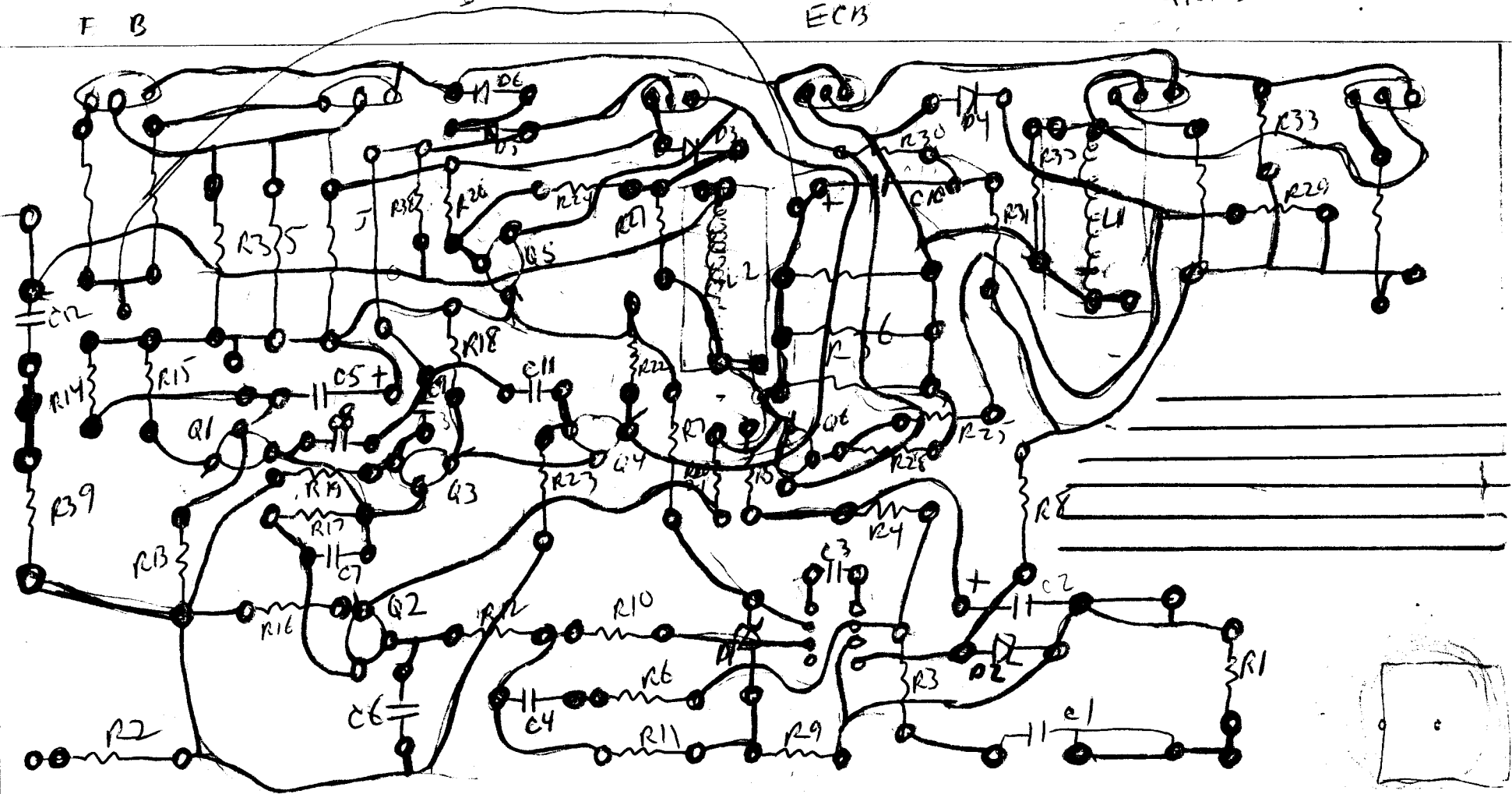
L1 — 1" DIA CORE
  - 2 LAYERS —16.5 TURNS TOTAL .25/LAYER
  - .6" LONG COIL
  - BOARD SPACING = 1.2"
    Lone .8" WIDE.

L2 = 12" LONG   OR 1.5" CORE
    x.5" WIDE   x .6 W   8.24T
    TOT

L2 = 1" DIA CORE — 2 LAYERS
   - 9.6 TURNS TOTAL 4.8/LAYER
   .35" COAL — Bd — 1.2" CONEX
                    .5" WIDE