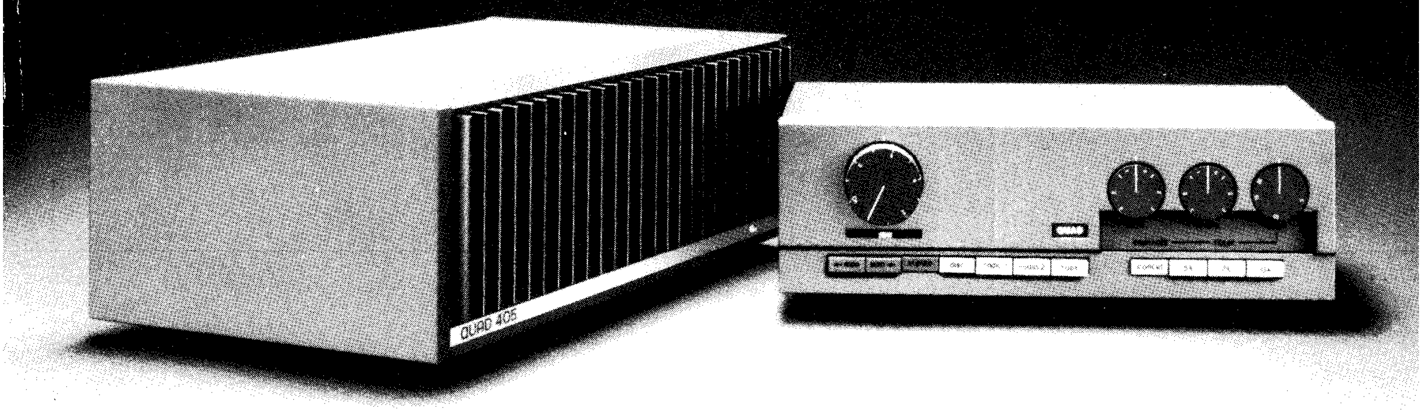
Test Reports

QUAD 405 Current Dumping Amplifier



QUAD

for the closest approach to the original sound

Quad 405 Power Amplifier

Gordon J. King

IN the beginning was the Class-B amplifier. Designers tended to prefer this to Class-A because of its better efficiency and hence power yield for a given size, heatsink and power transistor capacity; also to satisfy the greedy demands of loudspeakers with fast diminishing electro-acoustic conversion efficiencies. Pure Class-B is totally incompatible with hi-fi owing to the displacement of the two halves of the push-pull output transfer characteristics, leading to serious crossover discontinuity, and hence so-called crossover distortion, particularly at low signal levels.

Class-B was brought into the hi-fi realm by biasing the output transistors towards Class-A so that at zero drive the transistors were not cut-off completely but passed a degree of emitter/collector current, called quiescent current. Although still often referred to as Class-B, such amplifiers are really Class-AB.

Crossover distortion is impossible from properly designed Class-A amplifiers, but it can occur in relatively small doses from Class-AB amplifiers. It tends to diminish as the biasing is adjusted towards Class-A, but then the efficiency falls and the standing temperature of the power transistors and their heat-sinks rises. A compromise between efficiency and crossover distortion is worked out, and the remaining distortion is reduced by various artifices including, in some cases, large amounts of negative feedback.

When the design has been handled correctly the net result is an amplifier of very low distortion and relatively high efficiency. Indeed, crossover distortion is practically undetectable from some of the best Class-AB designs. However, to achieve this ideal state of affairs a large amount of design detail is essential, and components and adjustments can become critical. In spite of thermal compensation, the optimised conditions can be impaired by temperature changes and hence by the immediate past history of the programme energy and dynamics.

If intermodulation distortion is measured at very low power, around 1 mW, and then measured again at the same power but this time immediately following a burst of higher power operation, some Class-AB amplifiers will give a much higher figure on the second measurement, thereby proving the thermal point.

The design team at The Acoustical Manufacturing Company Limited have been aware of this shortcoming for some time, also of the critical nature of adjustment required to secure the best distortion performance from Class-AB amplifiers of conventional design. The aim, then, was to design an amplifier of exceptionally low distortion and of realistic contemporary power which relies far less on critical adjustment and thermal tracking. The result is the new Quad *405* power amplifier, which I have been analysing in great detail over the last few months.

The design employs a modified version of a technique known as 'feedforward'. This is not new to amplifiers in general, having been used and experimented with for some years now in connection with carrier systems and communal aerial systems.[1, 2] It has also been mooted for audio amplifiers,[3, 4] but so far as I can discover Quad are the first to use it in a commercial hi-fi amplifier.

The basic feedforward system uses two amplifiers, the main amplifier and an 'error' amplifier. The main amplifier performs the normal function of amplification with its inevitable addition of errors in the form of noise and distortion. By isolating the error signals from the fundamental signals it becomes possible to reinsert them back into the main signal path in such a way as to lead to their elimination. One way of isolating the errors is to sample the output and then subtract this from a sampled portion of the input, at the same time taking account of the delay time of the amplifier by delaying the sampled input by an amount equal to the amplifier delay. This secures synchronisation of the input and output samples, the two then being subtracted to leave only the errors.

Since the sampling circuits attenuate the error signals, the signals must be boosted before being reinserted into the main signal path, and this is the job of the error amplifier. Again, the delay resulting from this amplification must be taken into account to achieve complete cancellation.

Although based on this principle, the feedforward of the Quad *405* is applied within the loop of a feedback amplifier, the circuit carrying an error component which bypasses the power transistors, thereby reducing their requirements in terms of highly critical linearity. The Quad team has coined the term 'current dumping' for this technique.[5]

The amplifier (each channel) is arranged in the form of a feedback bridge whose active elements consist of a small but ultra-linear Class-A amplifier for providing the required swing of output *voltage* but at relatively small current, and the more usual large power transistors on a front heat-sink for providing the higher power *current* demands. Since it is the job of these transistors to provide the majority of load current, as dictated by the programme signal, they are appropriately called 'current dumpers'.

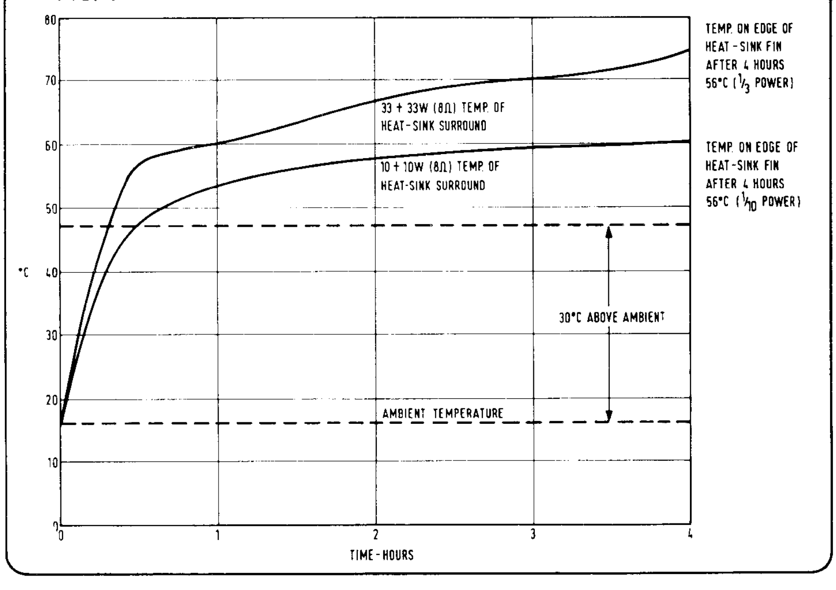
In other words, the main amplifier is of quasi-Class-B design, while the Class-A element can be regarded as a sort of 'control amplifier', which neatly deletes substantially all the distortion of the main amplifier. This clearly avoids the need to optimise the adjustments of the main amplifier critically, for whatever error there is in the output signal, the circuit cancels it out. Thus any drift or suchlike due to thermal happenings becomes insignificant!

In theory, the technique makes it possible to cut the errors essentially to zero, depending on the excellence of the Class-A amplifier. In practice there is always bound to be some residual non-linearity, albeit very small. Cancellation is also governed to some extent, though not critically so, by the balance of the bridge; but to maintain 'perfect' balance over the entire spectrum would appear to fall outside the reaches of the economy dictated by a design other than for critical laboratory purposes. Nevertheless, the *405* is an amplifier of astonishingly low distortion; it is, in fact, one of the purest which has so far passed through my laboratory, putting quite a demand on £10,000-worth of measuring equipment. The manufacturer intimates that even with a 5% error in bridge balance—resulting from a 5% error in any component value of the design—the maximum intermodulation products will still be down to the 5 μV level at 1 kHz; the maximum possible IMD being 0·01%, and the maximum absolute level of these components being some 140 dB below full power.[5] The spec. puts the total of all distortions in the range 20 Hz-20 kHz at least 80 dB below the rated power, corresponding to 0·01%.

The power and distortion parameters of the test sample were examined in significant detail, as brought out in the test results. The full 100+100 W of power into 8 Ω resistive loads was readily available, and this power held from 10 Hz to 20 kHz without ill effect. The heat-sink constitutes the front decor of the amplifier, and with steadystate drive this soon started warming up.

In accordance with our practice nowadays, the amplifier was preconditioned at one-third rated power (the power at which a Class B amplifier is running least efficiently and hence dissipating maximum heat) at 1 kHz with both channels driven simultaneously into 8 Ω resistive loads. After an hour's operation under these conditions the top surround of

FIG. 1 QUAD 405



the heatsink was far too hot to touch, it being exactly 60°C, from an ambient temperature of just over 16°C. The curves in fig. 1 show how the temperature builds up over a period of four hours both at one-third rated power and 10+10 W. These measurements were made with a Comark Electronic Thermometer, Model 1601 with specially calibrated thermocouples. Although certainly high, the temperature is still well within the rating of the output transistors, whose limit is 120°C, corresponding to a sink temperature of about 90°C.

The curves also show that the amplifier will safely survive and readily pass the FTC (Federal Trade Commission—American) spec. However, to get the BS 415 ticket the design would need to include a thermal cut-out to prevent the exposed temperature from rising much over 30°C above ambient under sinewave drive.

Quad are not the only manufacturers in this quandary. I have full sympathy with latter-day designers and feel that it is about time this crazy anomaly was resolved by the standards people. It is really academic, of course, because on music signal of normal dynamic range the amplifier remains relatively cool, even when producing loud peaks. Few people listen to sine-waves, though I suppose some of the modern electronic music can resemble steadystate information. My reason for labouring the point is merely to put it into proper perspective once and for all.

Based on distortion factor, the readout was in advance of 0·01%, but by calculating out the noise the spec. was adequately met, as shown by the test results. Marconi and Hewlett Packard wave and spectrum analysing equipment was employed for the IMD measurements, and Radford equipment for the distortion factor measurements. Two distortion factor residual oscillograms are given (fig. 2). The dual oscillogram shows 1 kHz signal with its residual at the top and 20 kHz distortion with its residual below, both with the amplifier operating at 10+10 W into 8 Ω resistive loads. In both cases the gain of

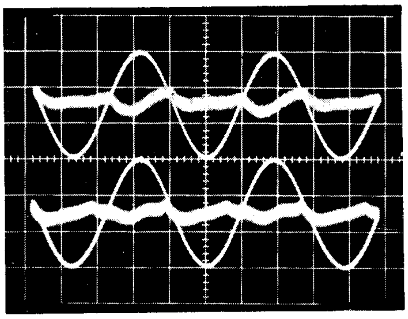


FIG. 2. *Dist. factor with 60 dB (1000×) gain. 10+10W 8 Ω. Top: 1 kHz. Bottom: 20 kHz.*

the distortion measuring channel was adjusted for exactly 60 dB (1,000 times) with respect to the sine-wave across the load. This presentation makes it possible to evaluate the peak distortion at both frequencies from the traces direct. The mean distortion (as indicated by the instrument) to the peak distortion gives an indication of the 'roughness' of the residual. A unity ratio would obtain from pure harmonic residual devoid of spikes.

Minor traces of crossover effects are indicated by the residuals, but these must be considered in the light of the extremely small mean distortion factor which, as the test results show, is little more than a mere 0·01%!

The other distortion factor oscillogram of single trace (fig. 3) was obtained at 1 kHz, with the amplifier's full 28 V RMS across a load consisting of R and C (*i.e.*, R−jX) which, at 1 kHz, was adjusted for an impedance of 8 Ω, the power factor being 0·75 and the phase angle 41°. Such a load is more representative of a loudspeaker than a pure resistance, though it must be noted that some loudspeakers present a much more complicated load to the amplifier, as my recent researches into amplifier/loudspeaker interface problems have dramatically indicated.

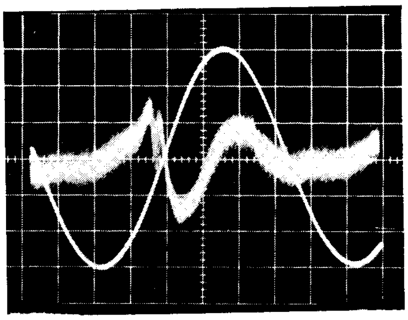


FIG. 3. *Dist. factor across R−jx load (8 Ω) with 70 dB (3162×) gain. 1 kHz 28V RMS. Pk. dist.=0·016%.*

Nevertheless, the simple impedance does put out-of-phase current through the output transistors, and when an amplifier is producing its full load voltage the current in the output transistors can precipitate the action of the voltage-operated (the voltage arising from the current through a resistor) current limiters *before* the full voltage output of the amplifier is reached. Bad distortion can thus be generated prior to the peak clipping of the sine-wave or programme signal.

The oscillogram shows that the Quad limiter (on one half of the output stage) was *just* coming into action at full output voltage, but even then the mean distortion measured on the Radford equipment was still at a very low level.

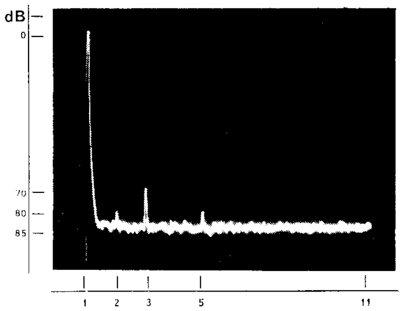


FIG. 4. FREQUENCY IN kHz.

Using the Hewlett Packard spectrum analyser, the spectrogram in fig. 4 shows the third harmonic at −70 dB and both the second and fifth harmonics at −80 dB from a 1 kHz fundamental producing 28 V RMS across the R−jX load. The spectrogram in fig. 5 shows harmonics and intermodulation products generated from two driving signals at f_1=5 kHz and f_2=9 kHz when each is

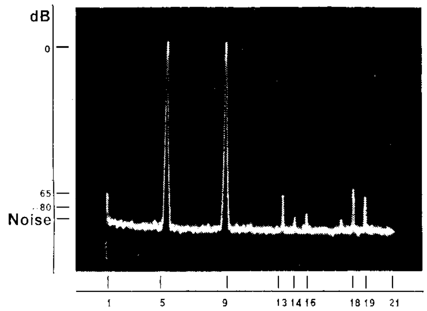


FIG. 5. FREQUENCY IN kHz

producing 14 V rms across the same load. The third-order products at 1 kHz and 13 kHz are each about 66 dB down. It is interesting to note that the second-order products are much lower, that at 4 kHz being pretty well into noise and that at 14 kHz about −80 dB. The component at 18 kHz is the second harmonic of the 9 kHz source (Sugden oscillator). The second harmonic from the 5 kHz source (Radford oscillator) is below noise.

That, then, concludes our detailed analysis of the distortion performance of the *405*. Under the more general conditions of measurement the distortion is well down to −80 dB (0·01%); but slightly higher amplitude products can be evoked by the use of more stringent test procedures. However, even in the worst case the amplifier has very low distortion by anyone's standard. The analysis has also indicated why relatively simple test methods with inexpensive instruments can no longer be expected to reveal the true performance of state-of-art amplifiers.

I was pleased to discover that the Quad team have deliberately avoided designing for a crazy RF response. The rise-time was a sensible 7·5μs, with the small-signal upper-frequency −3 dB point around 48 kHz. The small-signal response would appear to suit the speed of the 'current dumpers'. To ensure that the amplifier is fully able to 'digest' the speed of the signal fed to it (as dictated by the speed of the 'dumper' transistors used), the Quad spec. includes an *input* slewing-rate limit, given as 0·1 V/μs, and the distortion performance is based upon the rate of change of input signal not exceeding this limit, which corresponds to an upper-frequency of around 22 kHz.

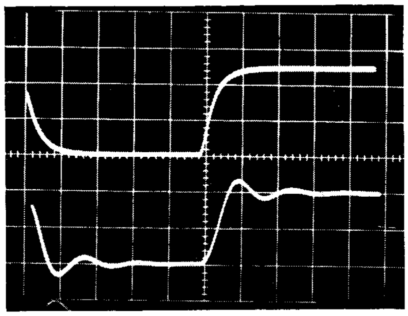


FIG. 6. *10 kHz square-wave response. Top: 8 Ω. Bottom: 8 Ω/1 μF.*

Our measurement of *output* slewing-rate worked out to 5 V/μs, which is virtually the same as the input spec. times the gain of the amplifier.

The step-function oscillogram (fig. 6) shows the rise-time across 8 Ω load at the top and the settling-time across 8 Ω in parallel with 1 μF below, both on a sweep of 10 μs/div. Although the latter produces mild ringing, this is swiftly damped.

The 20 Hz-20 kHz frequency response (straight line!) is shown in fig. 7, the high-pass filtering at the left of fig. 8 and the HF roll-off at the right (note the difference in frequency scaling).

Both channels matched fairly closely on all parameters, and the residual off-set, hum and noise, stereo separation and damping factor were well within specification.

Although quite small, the amplifier is of very 'solid' construction. As already mentioned, the front of the amplifier consists of the heat-sink. The amplifier is metal-encased and finished in the conventional Quad colouring. At the rear is a panel accommodating two pairs only of spring-loaded loudspeaker connecting terminals, polarity and channel identified, a mains input voltage adjuster, mains fuse, three-pin mains connector and four-pin DIN socket (with plug and connecting cable supplied) for the left and right input signals.

The DIN signal cable is terminated at the far end by two 'phono'-type plugs for accepting signal from a preamplifier, but personally I would have also liked to have seen the provision of two 'phono'-type sockets actually on the amplifier's back panel—in addition to the DIN socket which correlates with the Quad *33* preamplifier socketry. Perhaps Quad had this in mind at one stage since there are two holes (covered) close to the DIN socket where they could easily be accommodated.

Electronic design is very substantial, as one has come to expect from British Quad, and the power amplifier sections are built on the 'module' basis allowing easy service and interchange.

Unquestionably one of the very best British amplifiers on the market today, it is incredibly 'smooth' sounding and fully lives up to its specification. It packs sufficient power for the larger system; but remember the heat-sink will rise significantly in temperature when the amplifier is driven with sine-wave signal. The mains lead supplied is two-core with American-type two-pin plug termination. However, to satisfy BS 415 a three-core cable can easily be used (one conductor for direct earthing) since the three-pin mains socket has an earthing pin. When the *405* is used with the Quad *33* control unit, earthing will be accommodated via the braids of the audio connecting cable.

The amplifier is directly coupled to the loudspeakers, and protection is by fuses and by electronic current limiters. Useful comment about loudspeaker protection is given in the instruction book, which also gives information on the connection of headphones, additional loudspeakers and unbalanced and floating 600 Ω line inputs.

By the insertion of 1·8 k Ω resistors (two supplied, one for each channel) into sockets on the printed circuit board labelled R11 (a fiddly little job), the output voltage of each channel is limited to about 28 V peak (20 V RMS) ref. peak clipping. To avoid damage to the loudspeakers, this minor modification is necessary when the amplifier is partnered with the Quad electrostatics. Measurements made following this modification proved that

FIG 7 QUAD 405 FREQUENCY RESPONSE

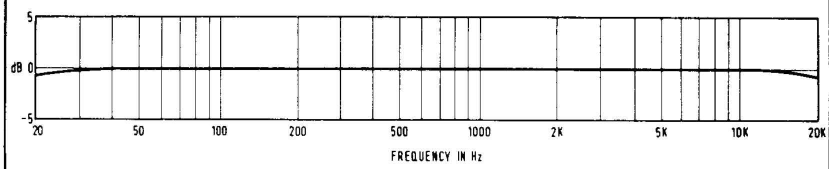
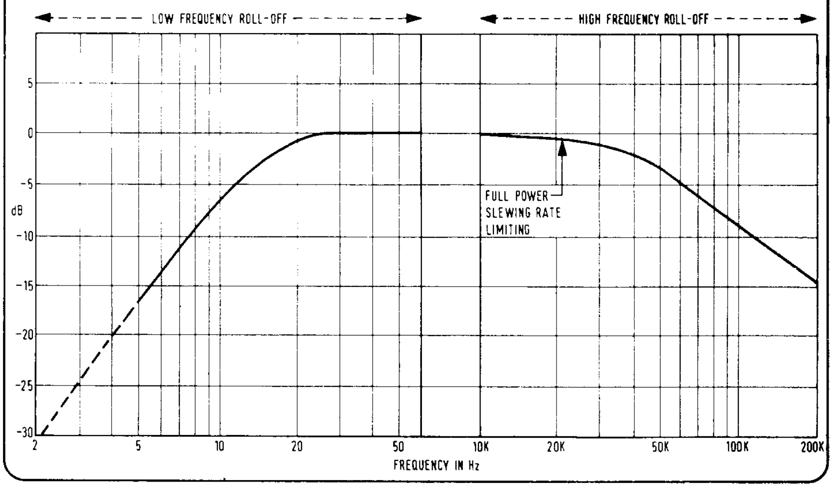


FIG. 8 QUAD 405



the clipping threshold was reduced to 28 V peak across 8 Ω resistive loads and to about 25 V peak across 4 Ω resistive loads.

Using an impedance load of 5·4 Ω and 48° phase-angle at 400 Hz, the protection transistors commenced switching and causing distortion a shade before the onset of peak clipping owing to the out-of-phase load and hence transistor current with respect to the voltage (see fig. 9).

A review of a Quad power amplifier can hardly be regarded as sufficiently exhaustive without trial in conjunction with a Quad electrostatic loudspeaker and Quad *33* control amplifier. The system in this form was established in a listening room of some 62 m³, receiving signal from a Shure V15/III cartridge. A range of music material was assessed by a critical panel of five, including Donald Aldous and myself. There was complete agreement that the amplifier neither added to nor detracted from the disc record signal fed to the ELS model. The sound level at towards-full-power tests was monitored and no sign of overload or protection transistor switching was detected even with an RMS peak sound intensity as high as 100 dBa.

Peter Walker's design aim of 'a piece of wire with gain' has thus, in the colloquial sense, once again been met. The *405* packs more punch than the earlier *303* and tames better the higher frequency distortions; but it needs a very critical ear to say conclusively that one amplifier sounds better than the other at normal listening levels in the domestic scene. Indeed, there are still those enthusiasts who swear by the even earlier Quad 22/II *valve* amplifier, and one of these at the time of writing has been removed from cold storage into my lab. and listening room

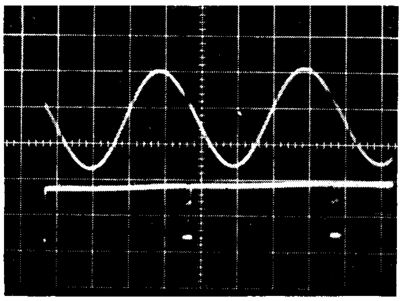


FIG. 9. *Protection transistor switching at 400 Hz when driving load of Z=5·4 Ω, φ=48° (voltage limiter on).*

for comparison with a contemporary transistor amplifier which scored high marks in a panel assessment test.

Desirable factors of transistor amplifiers over thermionic valve counterparts are their better power/weight ratio and efficiency, factors of significant importance when it comes to driving loudspeakers whose efficiency is a magnitude or so below that of speakers designed in the valve heyday. We certainly *do* need powers up to at least 100+100 W for realistic dynamic range in a fair size listening room and with loudspeakers of efficiency not much better than 0·1%. A valve amplifier would be a very massive animal to cater for this sort of continuous-wave power. The *405* is around the same size as just *one* of the early Quad valve power amplifiers, whose single-channel power is well below that of the *405*. However, perhaps it was the more graceful overload characteristics of valve amplifiers which enabled us, partly, to get away with less continuous-wave power!

There was no trouble at all in partnering the *405* with the *33* control unit. As already noted, the amplifier uses fuse protection. Some British designers and many Japanese ones prefer relay protection, which sometimes has three modes of operation. The contacts of the relay connect the loudspeakers to the power amplifiers only when the winding is energised. Energising current is derived from a DC transistor amplifier and time-constant circuit, which samples the power supply voltage. Thus, owing to the time-constant, the loudspeakers are connected *after* the supply stabilises, which avoids the switch-on 'thump' when direct-coupling is used to the loudspeakers, as it is in the *405*.

The relay control amplifier also includes a section which monitors the current in the output transistors, so that in the event of a beyond-threshold rise in current here, resulting, say, from a short across a loudspeaker circuit when the amplifier is under high drive, the relay contacts open and remove the supply. This method of protection tends to minimise the protection transistor switching effect and hence distortion (fig. 9) which can result from lowish impedance and large phase angles of the load (*i.e.*, loudspeaker), as already mentioned. However, a lab. study of the distortion generated by the two types of protection has revealed that the relay scheme is not always totally immune at high signal drive into a lowish impedance load of fairly large phase angle; that is, a curious type of distortion is sometimes produced *before* peak clipping of the sine-wave test signal. In general, though, the protection transistor arrangement shows up worse in this respect.

The third mode of operation is that the control amplifier also detects any abnormal rise in off-set voltage across the loudspeakers, the relay contacts then opening before the loudspeakers are damaged. The *405* relies on fuses for this protection.

Frankly, I would have preferred all-round protection as can be provided by a relay in the new Quad; but opinions can differ on this; and then, of course, there is the price to be taken into account. We cannot have it all ways. One must not get the mistaken impression that the *405* is not of rugged design. It certainly is; and of first-class competent engineering.

The amplifier is very easy to connect and use (there are no external controls), but must, of course, be operated from a good preamplifier/control unit, such as the Quad *33*. It was used in the domestic scene from music signal delivered by the preamplifier section of an integrated amplifier (not Quad), and worked without trouble or stress into IMF loudspeakers, which are noted for their insensitivity (and high quality). One of the test samples produced a mild mechanical buzz when used on a vibrant shelf; but electrically the amplifier was totally quiet. Our editor also discovered a slight mechanical hum on another sample, which was reported back to Mr. Walker who immediately put several models on test in a quiet room. This revealed some variation which has now been investigated and put right on the production line.

In summary, a well developed amplifier of novel conception which will go a long way to boost British audio exports.

References

1. H. Seidel: 'A Feedforward Experiment Applied to an L4 Carrier System Amplifier', *IEEE Trans. Comm. Tech.*, Vol. Com-19, Jun. 1971.
2. R. G. Meyer, R. Eschenbach and W. N. Edgerly, Jr: 'A Wideband Feedforward Amplifier', *IEEE Solid State Cir.*, Vol. SC-9, Dec. 1974.
3. 'Feedforward Error Control', *Wireless World*, May 1972.
4. A. M. Sandman: 'Reducing Amplifier Distortion', *Wireless World*, Oct. 1974.
5. P. J. Walker and M. P. Albinson: 'Current Dumping Audio Amplifier', *Wireless World*, Dec. 1975.

QUAD 405 POWER AMPLIFIER

Test conditions: Mains input 240 V 50 Hz. Both channels driven simultaneously from 600 Ω source.

PERFORMANCE		COMMENT
Power to clipping at 1 kHz	102 W (L)+101 W (R)	Into 8 Ω resistive loads.
Bandwidth at 100 W/8 Ω to clipping	10 Hz-20 kHz	Slewing-rate limiting ≃ 20 kHz.
Damping factor (BSI) at 40 Hz and 2 W	200	Includes R of connecting wires.
Frequency response (−3 dB) at 1 W	13 Hz-48·6 kHz	Also see graphs (Figs. 7 & 8).
Rise-time	7·5 μs	Also see oscillogram (Fig. 6).
Settling-time (8 Ω/1 μF)	20 μs	Also see oscillogram (Fig. 6).
Slewing-rate (8 Ω)	5 V/μs	20 kHz 28 V RMS approximately.
Input for 28 V/8 Ω	515 mV (L); 521 mV (R)	Digital instrumentation.
Hum and noise	0·4 mV (L); 0·45 mV (R)	Across 8 Ω.
Stereo separation	85 dB (1 kHz); 82 dB (10 kHz)	Ref. full power with non-speaking input shorted.
Offset	1·1 mV (L); 0·3 mV (R)	Well within spec.
Distortion factor at 10+10 W 8 Ω 20 Hz (including ripple) 1 kHz 20 kHz	 0·035% (mean) 0·012% (mean); 0·02% (p) 0·013% (mean); 0·02% (p)	Note that distortion *factor* includes noise. THD to spec. also see oscillograms (Fig. 2).
Distortion factor at 100+100 W 8 Ω and 1 kHz	0·0046% (mean)	Noise contribution 0·0032%.
Total harmonic distortion as above	0·0033% (mean)	Noise calculated out.
Distortion factor at 28 V RMS across R±jX load at 1 kHz	0·0076% (mean)	Slight limiter distortion present under this condition. See oscillogram (Fig. 3) and spectrogram (Fig. 4).
Total harmonic distortion as above	0·0069% (mean); 0·016% (p)	Noise calculated out.
Intermodulation distortion at 100+100 W and 1 mW:	no product greater than −80 dB into 8 Ω loads.	Measured all modes at 8 Ω *resistive*.

Note: L=R unless otherwise stated.

Main instrumentation: Marconi, Hewlett Packard, Radford and Keithley

Quad 405 Power Amplifier

Hugh Ford

IT is always exciting when a new product appears from the stable of the Acoustical Manufacturing Company, who have a long standing reputation for very high quality audio equipment and of course were the originators of the world famous Quad electrostatic loudspeaker.

The New Quad *405* power amplifier is the practical embodyment of the 'Current Dumping Audio Amplifier' described at the 50th Audio Engineering Society Convention by Peter Walker and Mike Albinson. Before proceeding with the details of the review I think that it is appropriate to quote in full the introduction to the paper: 'A new audio amplifier output stage in which the linearity of the main current carrying output transistors has no bearing on the overall amplifier performance, hence the need for biasing and allied problems associated with crossover are eliminated.'

In abbreviated terms, the principle of operation of this new amplifier is that a low power Class A amplifier with full voltage drive capability is used to drive the load at powers up to a few watts. Such an amplifier may be extremely high quality and not complicated if it is not required to have a high current drive capability. Now, the current drive from this Class A amplifier is sensed, and this is used to control two current dumping transistors which need not be matched as their dumping current is monitored and fed back to the input of the Class A amplifier. It follows that the high current transistors need not be matched, nor is their temperature stability of interest as there are no crossover biasing circuits.

The Quad *405* takes the form of a two channel amplifier based on these principles, each channel being rated at 100W into 8 ohms, which is more than adequate for domestic applications and is sufficient for many studios—that is all studio requirements where the producer doesn't want to 'feel the sound' with less efficient loudspeakers.

The presentation of the amplifier is most workmanlike, with the entire front of the amplifier taking the form of a finned heatsink to which the individual channel amplifiers are bolted as sub-assemblies. The remainder of the housing comprises the moulded plastic sides which are bolted to the heatsink and to which the two 'L shaped' covers are bolted, metal inserts being moulded into the plastic sides to take the bolts where required. No controls as such exist on the amplifier, that is with the exception of the mains voltage selector which covers all the common mains voltages. The power input is via a standard IEC connector, with its associated IEC standard fuseholder which is properly identified with the appropriate fuse ratings.

Signal connections take the form of a four pin DIN socket for the input—I loathe DIN connectors, but this type of connector has been used for the sake of compatibility with the Quad type *33* pre-amplifier. The speaker outputs are spring loaded connectors which take bare wires or AMP pins, and whilst terminal/sockets are much more convenient these are no longer permitted on high voltage amplifiers as a result of International safety regulations. I've never heard of anyone being killed by 100W of music, but it could be a very painful shock.

Internally tne standard of construction is really excellent, with first-class standards of wiring and construction. Each amplifier is in its entirety accommodated on a single printed board and maintenance is facilitated by every component being identified by screen printing on the boards. Furthermore, a complete amplifier channel may be removed by taking out four screws and then only five push-on type blade connectors. In addition, the instruction book includes a full circuit and parts list, plus the specification and operating hints.

Power output and distortion

As is my normal practice, very great care was taken to produce accurate results, stabilised power being used to feed the amplifier and accurate (0·1%) digital voltmeters being used to determine voltage levels.

Initially, the power output at the onset of clipping of a 1 kHz sinewave was determined with the following results:

	Output power	
	Left	**Right**
8 ohm load, both channels driven	122W	117W
8 ohm load, single channel driven	110W	107W
4 ohm load, both channels driven	68W	84W
4 ohm load, single channel driven	60W	78W

These levels are well above the rated power in the case of eight ohm loads and the amplifier did not take exception to driving into eight ohm loads continuously at very high levels. However, in the case of four ohm loads the available power was found to be very temperature sensitive, the above figures being obtained with the amplifier at its idling temperature; that is, the amplifier was left switched on with no signals applied at an ambient temperature of 20°C. Fig. 1 shows output power for 0·1% distortion at 1 kHz into four ohms and also dumping transistor case temperature plotted against time from idling temperature. It is to be seen that after about six minutes full power (0·1% total harmonic) operation the amplifier has stabilised its continuous drive capability at around 65W into four ohms, but the transistor temperature still continues to rise.

The real point about this issue is that certain loudspeakers with a nominal eight ohm impedance can show practical impedances as low as five ohms at selected frequencies and under these conditions (as with virtually all amplifiers) we are well down in available power; in the case of the Quad *405* the published curves for four ohms loads are rather optimistic, as they display conditions as may be found with a cold amplifier.

Anyhow, returning to the eight ohm performance, the measured distortion at 100W and below into eight ohms was astoundingly good as follows:

	Total Harmonic Distortion	
	Left	**Right**
100 Hz	0·007%	0·006%*
1 Khz	0·007%	0·006%*
10 kHz	0·028%	0·011%
20 kHz	0·055%	0·08%

* mainly noise

Analysis of the individual harmonics on a single channel gave results at 1 kHz and 100W into eight ohms of 0·005% second and 0·001% third harmonic, and at 1W 0·003% second and 0·004% third harmonic—really excellent results.

Likewise, the distortion performance at 50W and below into four ohms was first-class, the following total harmonic measurements being made: at 1 kHz - 0·014%; 10 kHz - 0·02%; 20 kHz - 0·05%. Harmonic analysis at high frequencies showed that the main harmonic was the second and also that there was a notable absence of crossover distortion as is shown in Fig. 2, which demonstrates 0·011% total harmonic distortion at 10 kHz.

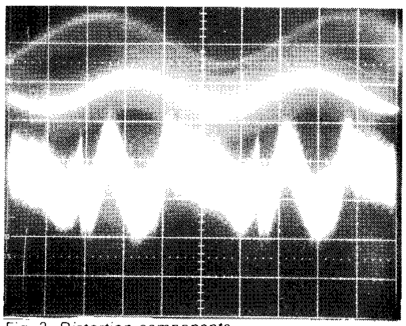
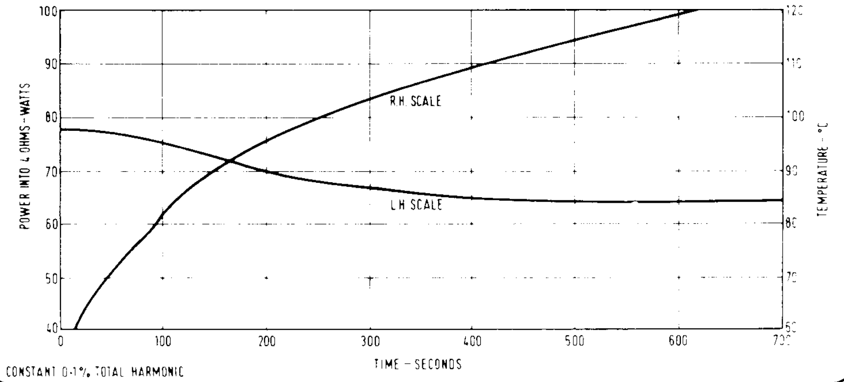


Fig. 2. *Distortion components 0·011% at 10 kHz.*

As is to be anticipated, the measured levels of intermodulation distortion were very low, the SMPTE method using 50 Hz and 7 kHz tones in the amplitude ratio 4:1 giving 0·006% at 100W peak equivalent sinewave into eight ohms; it was impossible to measure meaningful results at lower levels due to noise masking the very low distortion products. A notable point made during all the distortion measurements was that the addition of a 2 μF capacitor in parallel with the eight ohm loads made negligible difference to the distortion—an unusual feature of considerable significance.

FIG. 1 QUAD 405 POWER / TEMPERATURE / TIME CHARACTERISTICS



Before leaving the power output aspect of the amplifier it should be mentioned that by adding a single resistor to each channel (the resistors are supplied with the amplifier) the available voltage drive at the amplifier's output can be limited to 20V rms, so that it is safe to use the Quad *405* with loudspeakers of lower power ratings when this modification is incorporated.

Frequency response and noise

Fig. 3 shows the overall frequency response of the amplifier at 1W into eight ohms and it is noteworthy that this response curve is not only identical for both channels, but also that an identical plot was obtained at 100W into eight ohms. It is particularly nice to find that the frequency response has been carefully tailored at both the high and low frequency end—loudspeakers are just not interested in working below 20 Hz or above 20 kHz and furthermore can be easily damaged by high level 'out of band' signals.

Noise at the output was measured in terms of rms noise relative to 100W output into eight ohms with the following results:

	Left channel	Right channel
Unweighted 20 Hz to 20 kHz	−88·2 dB	−88·4 dB
Unweighted 15·7 kHz bandwidth	−90·0 dB	−89·9 dB
'A' Weighted	−92·8 dB	−92·5 dB
CCIR Weighted ref 1 kHz	83·6 dB	−83·4 dB

It is to be noted that while the 15·7 kHz bandwidth figure is just on the manufacturer's specification, the 'A' weighted figure falls slightly short of specification. Generally, it is felt that the noise performance meets realistic requirements and it was pleasing to find that hum levels in the output were well below noise.

Inputs and outputs

The input sensitivity for 100W output into eight ohms was found to be 0·512V on both channels, with either or both channels operating. Measurement of the input impedance gave an input resistance very close to the specified 20000 ohms on both channels in parallel with 230/240pF which is a realistic impedance for matching modern pre-amplifiers. It should be noted that the capacitive component of the input impedance correlates with the current specification, but that the specification has been modified from 50 pF.

Fig 4 shows the relation between the output impedance and frequency, and serves to confirm the specified output impedance of 0·03 ohms in series with 3·3 microhenries. This works out as a damping factor of 267 relative to eight ohms, a figure which will satisfy the damping factor addicts.

Investigations into the amplifier's stability gave first-class results. Overload recovery was also most impressive, the recovery from short tone bursts 10 dB into overload being absolutely clean with no visible distortion outside the overload burst. A less kind test is to drive the amplifier into overload with an asymmetrical waveform. Fig. 5 shows the result of such a test where 1 kHz asymmetrical waveform as shown in the lower trace has been fed to the amplifier the output of which is shown in the upper trace.

Overall phase shift is small within the audio frequency band as shown in Fig. 6, and as is to be expected the phase shift increases outside the audio band as a result of the intentional band limiting filters.

Interchannel cross talk was found to be extremely low and far better than specification −7 dB better at all frequencies. In fact, during all amplifier measurements it made virtually no difference if either or both channels were driven, so the power supply design must have been given considerable attention in the design process.

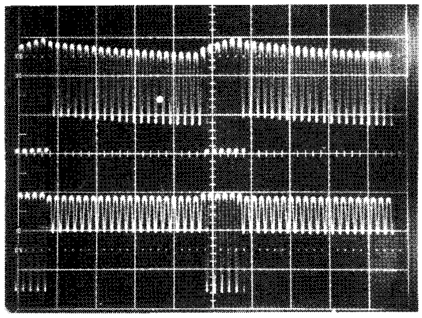


FIG. 5. *Asymmetrical waveform, response 1 kHz*

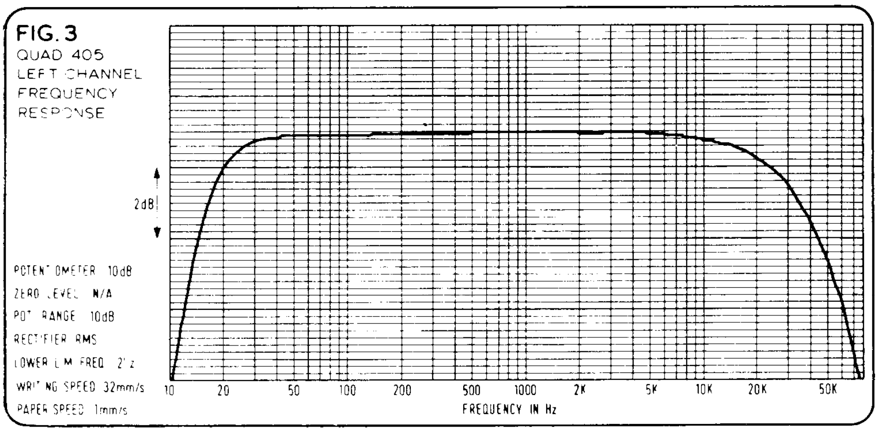


FIG. 3 QUAD 405 LEFT CHANNEL FREQUENCY RESPONSE

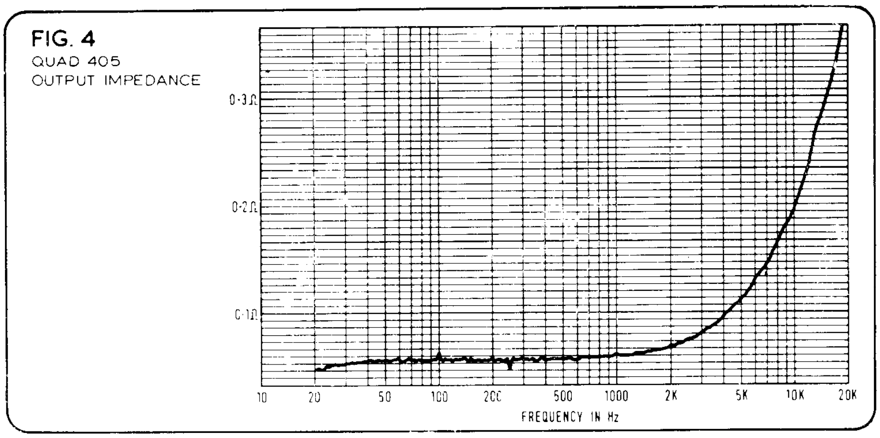


FIG. 4 QUAD 405 OUTPUT IMPEDANCE

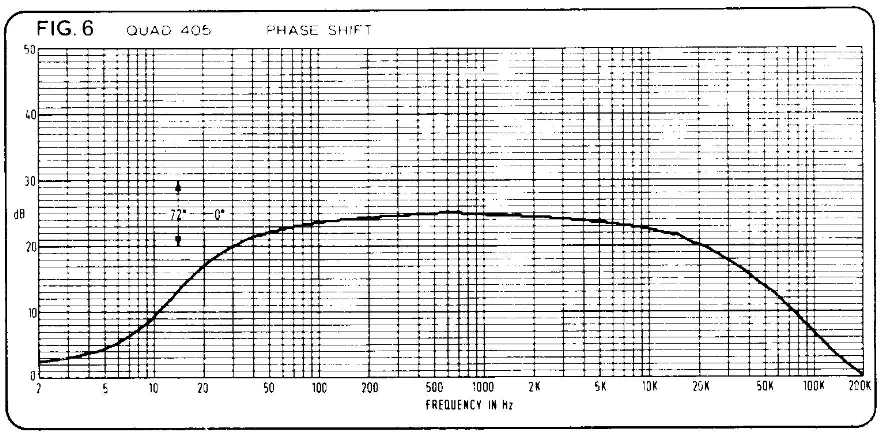


FIG. 6 QUAD 405 PHASE SHIFT

Summary

It is a reviewer's task to pick holes in equipment and also to mention its virtues: when a well respected manufacturer produces a new model every five or ten years it is for some good reason, as opposed to the 'this year's model' attitude of the less respected organisations who just change the colour of the knobs or add a couple of extra loudspeaker terminals for some gimmick which may have an equally gimmicky name.

The Acoustical Manufacturing Company has an excellent track record for amplifier design (let alone loudspeaker design), and in spite of the few criticisms which I have of the Quad *405* there is no doubt that this new amplifier ranks amongst the world's best power amplifiers.

For once I will break my rule of excluding subjective comments on equipment (which I regard as highly controversial) and stick out my neck—using a well known high quality loudspeaker which has a peculiarly awkward impedance characteristic the Quad *405* sounds superb.

From a point of view of domestic applications and of monitoring classical material I do not have any reservations about the Quad *405* but I would not recommend the use of 4 ohm loudspeakers—particularly if rock music is to be reproduced at high levels.

On the other hand, an amplifier more suitable for the latter type of use will cost two or three times as much as the Quad if one looks for equivalent performance, and there are few amplifiers which fit in this slot.

This leaflet is compiled from the following reviews:

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QUAD ***for the closest approach to the original sound.***

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