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'.

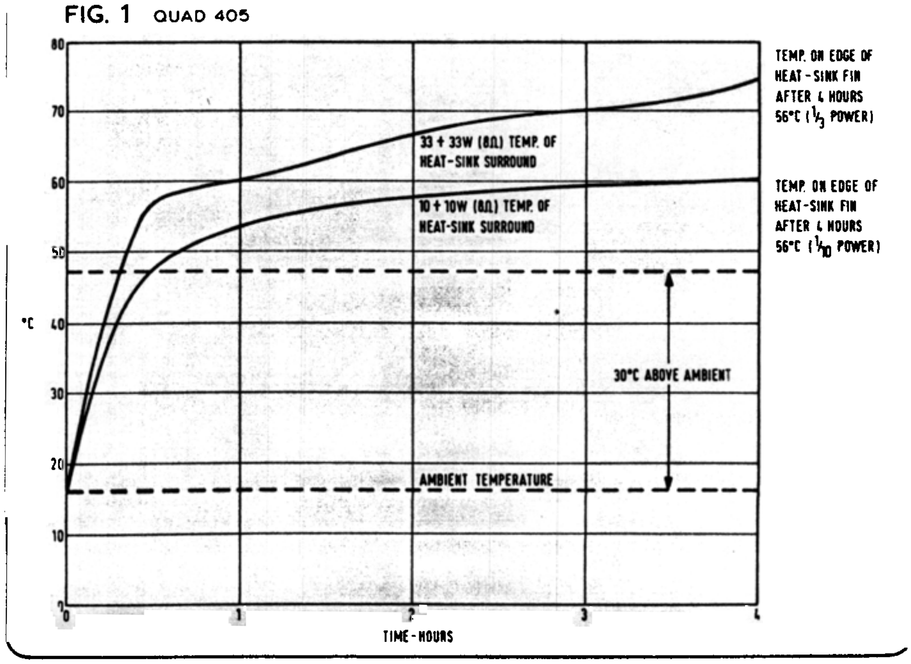
In other words, the main amplifier is of quasi-Class-B design, while the Class-A element can be regarded as a sort of 'control amplifier', which neatly deletes substantially all the distortion of the main amplifier. This clearly avoids the need to optimise the adjustments of the main amplifier critically, 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

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
iewave
d are not the only manufacturers in this
ary. I have full sympathy with latter-day
ers and feel that it is about time this
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,
when producing loud peaks. Few
listen to sine-waves, though I suppose
of the modern electronic music can
ole steadystate information. My reason
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perspective once and for all.

Based on distortion factor, the readout wa
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n factor residual oscillograms are
g. 2). The dual oscillogram shows 1
al with its residual at the top and 20
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the amplifier operating at 10+10 W intc
esistive loads. In both cases the gain of

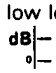
Minor traces of crossover effects are indicated by the residuals, but these must be considered in the light of the extremely small mean distortion factor which, as the test results show, is little more than a mere 0·01%

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−j× 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.



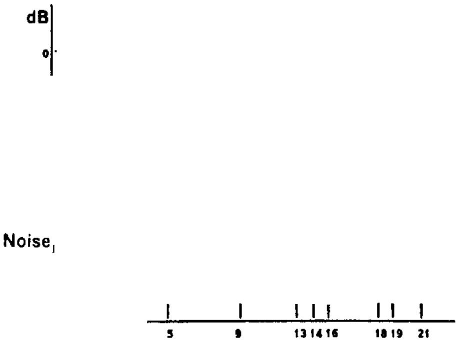


FIG. 5. FREQUENCY IN kHz

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

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