Audible amplifier distortion is not a mystery

Some things are believed because people feel as if they must *be true, and in such cases an immense weight of evidence is necessary to dispel the belief.* BERTRAND RUSSELL

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There is a very widely held belief that all amplifiers sound different, and that the reasons for this are so subtle and mysterious that no-one has yet properly understood them. I do not agree with these views, and confidently maintain that all first-class, competently designed, amplifiers, tested under completely fair and carefully-controlled conditions, including the avoidance of overloading, sound absolutely indistinguishable on normal programme material no matter how refined the listening tests, or the listeners, may be; and that when an inferior amplifier is compared with a very good one and a subjective quality difference is genuinely and reliably established, it is always possible, by straightforward scientific investigation, to find a rational explanation for this difference.

Subjective reactions

When people claim to have detected a difference in the sound of two amplifiers, the true explanation for this may be any of the following:

- the amplifiers actually did produce different audible distortions,
- there was a slight difference, probably unsuspected, in the test conditions,
- psychological factors were exerting an influence.

It is possible to be quite misled by some small physical effect, thought to be of no consequence at the time. I well remember a particular case some years ago when a friend claimed to be able to detect by ear the difference between a good valve amplifier and a good transistor amplifier. He invited me to his house and had a changeover switch which I was asked to operate, not knowing which position was which. I soon found I could indeed detect a slight difference, one position seeming just a little smoother and less "grainy" than the other. I supposed this to be the valve position, which was correct, and we were both pretty well convinced we were hearing a trace of crossover distortion. It then occurred to me to wonder just how accurately the volumes had been set to equality in the two positions, and the outcome of this was that we found that a reduction of not more than about 1dB in the volume from the transistor amplifier made it absolutely impossible for either of us to tell which amplifier was operating! More recently it was found that by choosing the moment of switchover in relation to the musical phrasing, to coincide with a change in sonority, one could produce the reaction that either one or the other of two systems was the better. This sort of thing can, of course, happen spontaneously, without anyone being aware of it. Another possible cause of deception is a trace of hum in one system but not in the other, due to insufficient care over earthing arrangements in the test set-up — this hum can get misinterpreted as a degradation in general quality.

With regard to psychological factors, I think it should be openly recognised that those of us claiming to have "golden ears" in matters of sound quality judgement can nevertheless be very easily led astray in various ways. For instance if, without being aware of it, we have listened for a long period to some equipment with, say, a 6dB dip in the frequency response at 3kHz, but otherwise of first-class performance, removal of the dip is very likely to produce the reaction, at least initially, that the reproduction has become too strident. However, if it was *known* to the listeners beforehand that a dip had been intentionally introduced, removal of it is then more likely to produce the reaction "Yes, now the violin tone is more realistic" or something of the sort! Such pre-conditioning and psychological influences are quite strong, and should be allowed for. Another psychological phenomenon, very significant I think, is that few of us like to admit that we "just cannot tell the slightest difference" in the presence of others who have professed to hear subtle differences. So most people will succeed in convincing themselves that they really have managed to notice small changes in sound quality. In properly conducted subjective tests, however, the participants should not know which system they are listening to at any given time, and the number of switchovers, some genuine and some not, should be large enough for a proper statistical interpretation of results to be made. Guesswork, maybe unconscious, is then largely prevented from influencing the results.

An amusing illustration of some of these psychological ideas arose on an exhibition stand by a well-known firm, who had arranged things so that visitors could listen, at precisely the same volume, to three of their amplifiers, being invited to identify the most expensive model. In fact it was found that voting for "the best amplifier" was about equally distributed between the three, so that, naturally, about a third of the visitors picked the right one. When told they had been successful, the almost universal reaction of these individuals was one of pleasure at their evident skill, whereas, of course, an equally logical reaction would have been to congratulate themselves on their good luck!

The BBC Research Department is well aware of the dangers of reaching quite wrong conclusions from subjective tests. Very careful precautions are taken to eliminate as many psychological and physical disturbing factors as possible, and even to derive, where appropriate, a quantitative estimate of the reliability of the results[3]. It is very evident that in many other places such precautions are not properly taken.

Recording systems and amplifiers

Unlike amplifiers, conventional tape and disc recorders, even those of the highest professional grade, have distortion levels and signal-to-noise ratio which are only just about good enough subjectively. A very instructive experiment is to record the same mono programme source on both tracks of a good stereo tape recorder, with a level difference of, say, 10dB. The replay gains are then adjusted to give outputs of equal magnitudes, and these are subtracted one from the other to give, ideally, nothing but noise and distortion. The distortion is mainly that of the more heavily recorded track, whereas the noise is mainly that of the weaker track. (In practice a little h.f., and possibly l.f., phase correction may be necessary to get fully satisfactory programme cancellation.) With gains set to give normal listening volume when only one track is reproduced, the distortion heard with both tracks operating is quite horrible and is loud enough to be very easily audible all over the room even in conditions of moderately high ambient noise level. This gritty, blasting, distortion is only somewhere about 40dB below the uncancelled programme level during loud passages, yet it is virtually unnoticeable when accompanied by the music. Tests with tone input show that the distortion is mainly third-harmonic, the percentage distortion being proportional to the square of the output voltage and reaching about 2% at peak recording level. The distortion is fairly independent of frequency over most of the audio band. Thus a first-class professional tape recorder gives distortion of about the same magnitude and character as a push-pull class A amplifier having a distortion figure of about 2%, assuming this also to be reasonably frequency-independent.

Experiments I have done with class A push-pull amplifier circuits, involving balancing out the programme and listening to the distortion by itself, do indeed show that it sounds much the same as that produced by a good tape recorder, and that 1 or 2% distortion is low enough for results of the highest quality, provided the amplifier performance is clean enough in all other respects.

Similar experiments with class B push-pull circuits, adjusted to give considerable crossover distortion, show, not surprisingly, that the distortion is rougher and more unpleasant sounding, and tends to be nearly as loud during fairly quiet parts of the programme as during the loud parts – it appears as an almost continuous background fuzz. For absolutely first-class quality, distortion of this type must be reduced to much less than 1% at all output levels and over most of the audio spectrum. This topic will be considered in greater detail later on.

In recording systems, unless very refined and expensive digital techniques are used, there is always the need for a careful compromise between signal-to-noise ratio and distortion. Compandor systems, of which 'dbx' is the latest, and very welcome, development[4,5], can achieve an impressive improvement in subjective signal-to-noise ratio, together with some reduction in peak distortion level, but they do not actually affect very greatly the signal-to-noise ratio existing during loud passages. Thus reliance is still being placed on the masking effect[6,7], whereby unwanted sounds, which would be very easily audible on their own, become virtually inaudible when accompanied by the wanted programme.

With amplifiers, on the other hand, it is comparatively easy to reduce the audible distortion and internally-generated noise to far lower levels than in any normal recording system, and this is what is done in equipment of the highest grade. Provided such amplifiers are tested under sufficiently carefully controlled and fair conditions, are free from faults such as hum and r.f. interference susceptibility, have insignificant differences in frequency response, and are not overloaded, the quite inevitable result is that one amplifier is absolutely indistinguishable from another, on normal programme material, no matter how "golden" may be the ears involved.

Quad have shown[8,9] that, with their transistor power amplifiers, if the amplifier distortion, including hum and noise, is reproduced by itself at its normal level, without the music, the result is *total silence* under ordinary listening conditions. This is enormously better than the result obtained when a somewhat similar test, as described above, is done on a high-grade professional recorder. But, to me, the most amazing thing is that Peter Walker tells me that few of the people who have witnessed this experiment seem able to appreciate its true significance, which is, quite inescapably, that such amplifiers are subjectively perfect with a large margin to spare and give an audible performance which can never be improved upon. Quad do not maintain, however, that theirs are the only amplifiers about which this may truly be said. Of course if, during the above experiment, such amplifiers are allowed to overload, even momentarily, the silence is broken and the distortion fairly cracks forth. But amplifiers should not be allowed to overload, and if they do, the only proper solutions are to turn the volume down or employ more powerful amplifiers.

A few people have raised the objection to the above experiment that though the distortion may be inaudible on its own, the ear and brain are exceedingly complex and subtle, and the effect of the distortion might conceivably be perceived when it is accompanied by the music. This, however, is quite contrary to what is found to happen in the tape-recorder experiment referred to earlier, where the distortion is easily heard on its own but is very well masked when accompanied by the music. Experiments I have done involving crossover distortion show that it too is fortunately subject to a considerable degree of masking in the presence of the associated programme.

A diagnostic tool

The technique employed by Quad[8,9] for listening to amplifier distortion by itself, on programme input, provides a very useful tool for assessing the subjective goodness of amplifiers in a quantitative manner and for establishing criteria that should be met if an amplifier is to be totally free from audible distortion. The technique can obviously be implemented in various detailed ways, and Fig. 1 shows one arrangement which is suitable when the amplifier under test is of the phase-inverting type. When, as is more usual, there is no phase-inversion, a very low-distortion phase inverter must be introduced into the circuit in one of several possible places.

For setting the circuit up, it is found in practice that an audio noise source is more suitable than normal programme input, since all frequencies are present all the time. Thus S_1 and S_2 are both closed, and P_1 plus the several adjustments in the frequency-response and phase-balancing network are adjusted for minimum output from the monitoring system. The potentiometer P_2 should initially be set to a low resistance value, the value being raised as the balance condition is made more and more nearly perfect. Potentiometer P_2 should finally be set so that, with S_1 or S_2 opened, the voltage fed to the monitor system loudspeaker is the same as that fed to the load circuit of the amplifier under test. With both switches again closed, the distortion alone will then be reproduced by the monitoring system loudspeaker at its proper level. Having thus got the circuit correctly set up – a rather tedious operation because of the number of adjustments involved – a little thought will show that a variety of interesting and very informative tests may then readily be done, such as:

- The gain of the monitoring system may be increased until the distortion does become audible by itself, thus obtaining a measure of the margin by which it was previously inaudible.
- The effect on the audible distortion of loading the amplifier under test with loudspeakers and/or dummy loads having various different impedance characteristics may be investigated. (When a loudspeaker load is used, it is necessary, of course, to prevent the sound from this loudspeaker from reaching the person listening to the distortion on the monitoring system loudspeaker. Rather than use well-separated rooms and very long leads, a more convenient procedure is to tape record the distortion and listen to it later on.)
- The two loudspeakers of Fig. 1 may be placed next to each other, P_2 then being adjusted to determine by how much the distortion may be increased above its "natural" level before a just-detectable degradation in music quality begins to become evident.
- With S_2 only closed, and then S_1 only closed, P_2 being set for a suitable listening volume from the monitoring-system loudspeaker, reproduction via the amplifier under test may be compared with that via the passive network. With a first-rate amplifier,

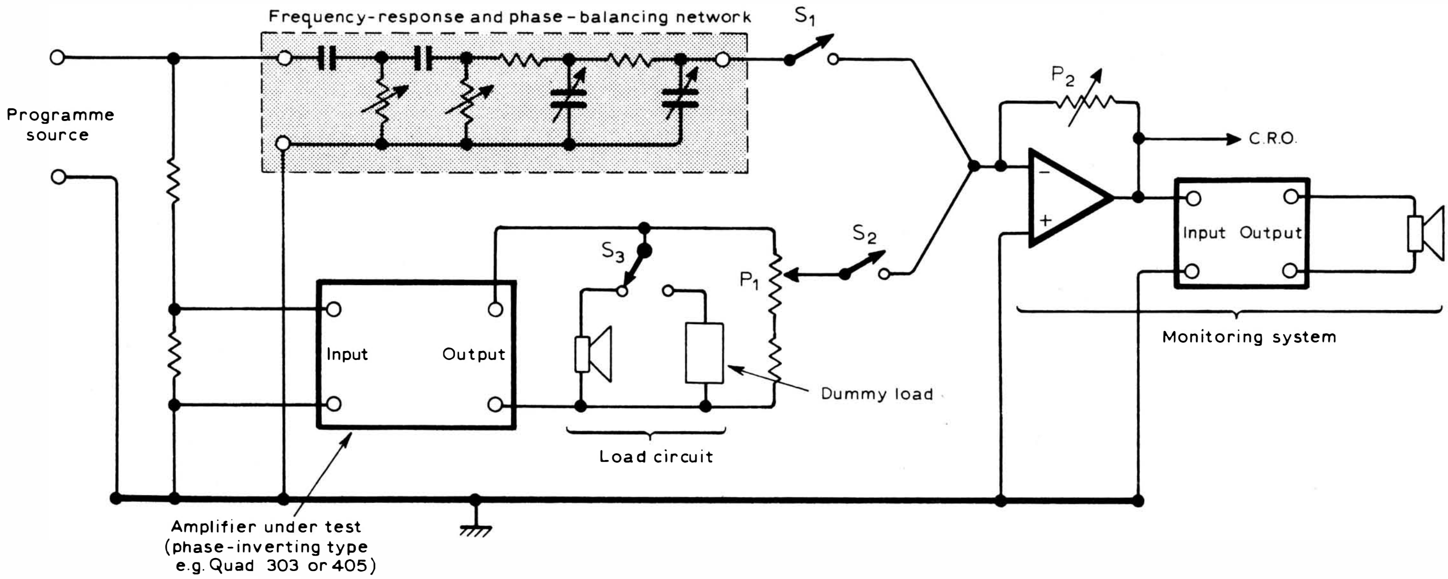

Fig. 1. The diagnostic set-up. A modified frequency-response and phase-balancing network may sometimes be required.

absolutely no difference whatsoever should be detectable on any kind of music programme input, provided that no overloading of the amplifier under test is allowed to occur. The test may be extended to assessing the degree of unpleasantness of various degrees of overloading, with and without protective circuits in operation, etc.

● When two amplifiers are found to sound genuinely different in ordinary subjective tests, they may then be tested in a circuit of the Fig. 1 type to see whether the distortion is audible when reproduced by itself. It may be found that the distortion is of an overloading type, though perhaps happening at a lower output level than the expected clipping level because of the operation of protective circuitry within the amplifier — or it may be that the amplifier has been badly designed with regard to its slew-rate capability. Such possibilities may then be looked into in detail. On the other hand, if both amplifiers give inaudible, or very unobtrusive, distortion, it is worth testing one amplifier in the Fig. 1 circuit with the frequency-response and phase-balancing values adopted for the other amplifier in place. Then, if there is a noticeable difference in quality when only S_1 or only S_2 is closed, the mid-frequency gains having been set to precise equality, it is likely to be because of the slightly different frequency responses — in particular, the response below the audio spectrum may be important in influencing the amount of rumble or other sub-audio-frequency signal reaching the loudspeaker, where it may cause large cone movements and thereby affect the loudspeaker distortion.

● By using an oscilloscope with the Fig. 1 set-up, much can be learnt about the relationship between the type of distortion waveform observed and the corresponding subjective nature of the distortion. The system also has the great virtue, when used with tone input, that the true waveform of the amplifier distortion is displayed, unaffected by oscillator distortion or by slight harmonic phase shifts contributed by the notch filter that would normally have to be used.

The Fig. 1 type of arrangement can also be made the basis for an accurate and very satisfactory technique for harmonic and intermodulation distortion measurement, which has the advantage of not demanding a high degree of oscillator waveform purity.

Some conclusions

One of the conclusions to be drawn from tests such as those just outlined is that amplifiers do tend to differ somewhat in the degree of unpleasantness of the distortion they produce when allowed to overload, but, apart from this I feel sure that nobody who has actually himself used these largely subjective investigational techniques could possibly continue to believe that all amplifiers sound different or that the subjectively perfect amplifier has yet to be designed. This is why Quad have been prepared to stake their reputation and say without reservation that they would be prepared to accept a challenge to have their 303 or 405 amplifiers compared effectively, using the Fig. 1 type of set-up, with what they have called a "straight wire with gain"[10] Provided certain quite reasonable test conditions are satisfied, their claim is simply that no-one will genuinely be able to detect the slightest difference in sound quality on any programme input derived from normal sources.

The unconvinced may well say "if subjective perfection has already been achieved, then why are amplifier manufacturers still devoting a lot of research and development effort to making better amplifiers?". The cynical reply might be "to produce even more impressive-looking figures for reviews"! But in fact the enlightened designer is probably spending most of his time struggling with far more difficult problems, such as how to achieve greater reliability, how to simplify the design and hence reduce the manufacturing costs, how to eliminate the need for preset adjustments, how to increase the maximum available output, how to improve the ability of the amplifier to cope with a wider range of load impedances, how to eliminate "switch-on plonks" etc. None of these problems directly involves the concept of subjective listening quality.

It is when problems such as those just mentioned are considered that the true nature of the enormous advances made in audio-amplifier technology becomes evident. In 1938, a British 14-watt high-quality amplifier sold for about £19, yielding a figure of 0.74 watt per £1. A recent 200-watt stereo amplifier, of smaller size and weight, sells at £115 and gives 1.7 watts per £1. Allowing for inflation, it is clear that the true cost per watt using modern solid-state techniques is down by a factor of the order of ten on what could be achieved in the valve era[2]. This is undoubtedly a great engineering achievement.

As a designer of audio amplifiers and other equipment, of which some is currently in use in BBC studios and elsewhere, I must have spent many thousands of hours inventing, thinking about and experimenting with audio amplifier circuits, but I cannot recollect ever having carried out subjective quality-assessment tests as a direct part of the design and development process. Subjective tests have been done separately from the design work and for the purpose of helping to establish criteria which need to be satisfied by the equipment designed.

Without knowledge of such subjectively-derived criteria, it is natural to "play for safety" and make the performance far better than it actually needs to be. This is particularly the case with preamplifier or control-unit design, where the non-linearity distortion is usually of the simple smooth-curvature type, which does not need to be reduced anything like as far as it is possible to reduce it in order to become quite inaudible. To elaborate the design, with consequent increase in cost, to the point where the distortion is, say, a hundred times, or more, below the subjective detection limit — which it is quite possible to do — is surely not in the true interests of the customer. Needless to say, very great care indeed must nevertheless be taken with things that really do matter, such as leaving sufficient "headroom" to accommodate all pickup sensitivities[2], achieving very low hum and interference susceptibility, etc.

Once the designer has freed himself from various quite irrational and unfounded beliefs, e.g. that there is an inherent subtle difference between valve and transistor sound, that transformers always produce detectable subjective distortion, that class B amplifiers can never sound quite as clean as class A ones, that feedback should only be used in small amounts, etc., he can then proceed in a proper scientific manner to develop designs of good economy and reliability, and immaculate subjective performance. He will appreciate that there are countless ways of designing equally good-sounding amplifiers, and concentrate his efforts largely on seeking the optimum engineering solution.

Amplifier reviews

The belief that all amplifiers sound different seems to be even more deeply rooted with the popular hi-fi press and their reviewing teams than it is with designers. I feel that a great disservice is being done both to the buying public and to some manufacturers by reports on amplifiers and control units of the type which have appeared, for example, in *"Hi Fi for Pleasure"*[11,12]. The reviewers claim to have been able to detect by ear specific deficiencies in virtually all units submitted to them, including differences between "cancel" and "tone controls flat" in all cases where such a comparison was possible. But ones incredulity is surely stretched beyond the limit when one finds a well-known control unit, widely adopted by discriminating professional users, described as having a mid-range that is forward yet lacking in detail, with some compression of peaks and an unstable image, and a top end performance that is thin and rounded off, but with a splashy character imparted on cymbals, and similar explosive sounds, the overall performance being summarized as dull, with a great loss of presence and ambience and "seeming to make the music sound amateur"! Enquiries revealed that the unit in question was subsequently retested by the manufacturers and found to be in perfect order. When descriptions such as the above, which could only properly apply to equipment with quite gross faults, are used in relation to items known to be first-rate, it is clear that either something was wrong with the test set-up or that the reviewers — not to question their sincerity — had fallen prey to their own imaginations.

Since the belief that all amplifiers sound different has become so widely accepted, it is natural for people to want to find technical explanations for it. Since little correlation with performance as ordinarily measured can be found, the notion has built up that something extremely subtle and elusive is involved. To explain these supposed subtleties, those with more imagination than scientific understanding proceed to evolve a series of wilder and yet wilder pseudo-scientific hypotheses. New jargon is created — "musicality", "loss of information", etc. An article of French origin which has recently appeared in *Hi-Fi News*[13] – accompanied, however, by an expression of editorial neutrality and non-commitment – says the quality of copper used in loudspeaker leads influences the quality of the information transmission, the best wires having a purity as high as 99.99995%. The alternating magnetic field generated by a loudspeaker cable is said to represent a significant loss of information. Even in the wiring of electric-bell circuits, the use of Litz wire is claimed to give "tintinabular superiority". How silly can we get? All this sort of thing, which seems to be encouraged by some of the hi-fi magazines, for whom it no doubt provides easy material for filling their pages, is surely not good for the future of the audio industry, being liable to bring it to a state of disrepute with intelligent people.

Admittedly the subtleties and difficulties of many aspects of good sound reproduction are enormous, but it seems a pity that an atmosphere of quite irrational mysticism should be encouraged to invade even those parts of the field where things are properly understood and quite straightforward.

Finally, lest some readers may feel that the views here expressed are representative only of an engineering outlook, it may, perhaps, be relevant to add that I have a passionate interest in music, that I frequently go to concerts, do a good deal of recording of live music, and that much music making, some professional, goes on in my household.

The next article will discuss some detailed technical matters relating to amplifier design.

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Harold W. Barnard

Many people in the electronics industry will be saddened to hear of the death of Harold W. Barnard, editor of *Wireless World* from 1965 to 1973. Although he held this post for only eight years he had in fact given a lifetime of devoted service to the journal. Starting in 1925 as an assistant to the production manager, he transferred in 1936 to the news side of the (then weekly) journal to become what was known as a "leg-man" – getting news the hard way without the assistance of today's information services and publicity organizations – and eventually took complete charge of the news section. During the 1939-45 war he was a member of a small team that kept the journal going under extremely difficult conditions. In 1959 he was appointed assistant editor, a fitting tribute to his journalistic abilities.

When he retired in 1973 we wrote this of him: "Kindness, courtesy and dedication are three qualities not very much in evidence in the modern industrial scene. They are the three qualities which one would most likely pick if one were asked to characterize in a few words the retiring Editor of *Wireless World*, Harold W. Barnard. Readers may wonder what such things have to do with technical journalism: they don't seem to be relevant to the business of turning out good articles and news on radio and electronics. But technical journalism, like many other professional and industrial activities, runs on the fuel of human contacts. What is printed in each issue is the final result of much talking, listening, letter writing, discussion, argument, persuasion, joking, threatening, criticizing, and praising. All these are necessary functions, but it is the personal qualities an editor brings to exercising them that makes all the difference. It would not be fanciful to claim that kindness, courtesy and dedication have been significant factors in the making of *Wireless World* during the eight years of Harold Barnard's editorship."