Dynamic Range versus Ambient Noise

A practical solution involving metal-cone loudspeakers and high-power amplifiers

by George Izzard O'Veering

The essential requirements for a high quality sound reproduction system are adequate power and adequate bandwidth. Since loudspeakers are inefficient, and the attainment of wide bandwidth systems is generally incompatible with high efficiency, the achievement of the desired acoustic spectrum from the subsonic to the ultrasonic makes heavy demands on amplifier output.

Moreover, it will be apparent on reflection that many of the musical and other instruments, the acoustic output of which it is desired to reproduce, are themselves both powerful and developed to a high degree of acoustic efficiency. It is clearly laughable to suppose that the majestic splendour of a full orchestral fortissimo or the lung power of a Wagnerian tenor in full cry can be represented adequately on an acoustic budget of a few hundred milliwatts. Inconvenient though it may be, there can be no doubt that to recreate the true dynamic range of much recorded sound over the required sonic spectrum makes demands on the output power of the audio amplifier/reproducer system which are well beyond the capabilities of most, if not all, of the equipment at present on the market.

Calculation of required power

The quietest sound which can be heard in a given environment depends entirely upon the background noise level of that environment. Unfortunately, most people live in close proximity to traffic, neighbours with television sets, dogs, and noisy children, and these things, together with the normal background sounds of the home, combine to give an ambient noise level of about 50dB. The minimum sound level which can be distinguished clearly above this background level is therefore 53dB. The dynamic range of orchestral music can be as much as 70dB, therefore in order to be able to hear the pianissimo as well as the fortissimo passages, a peak level of 123dB is required.

The acoustic power in watts required to produce a sound intensity level of 53dB is about 6μW for an average-size living room. Since a 10-dB increase in power output requires a tenfold increase in power, the 123-dB peak-power level will therefore require a maximum acoustic output of some 50W. If the loudspeaker efficiency is 5% (and this is significantly better than is obtained from most commercially available loudspeaker systems) a peak-power output of 1000W per stereo channel is obviously required if the total dynamic range of a symphony orchestra is to be heard in comfort.

It was clear from discussions both with manufacturers and distributors that no serious attempt had been made to meet the requirement for drive units capable of handling as little as 250W. Initial trials made with some of the more likely units, were generally unsatisfactory. In particular there was a tendency for the cone and speech coil to become detached, and for fraying of the surround. In addition, the failure was often made more serious by partial combustion of the inflammable materials within or in proximity to the speech-coil assembly.

When more substantial reproducer units had been evolved, this only brought to light the flimsy nature of the housings which had been supplied, and considerable annoyance was caused by a minor injury sustained when one of the cabinets burst during an orchestral transient and the room was filled with flying splinters. At this stage it was accepted that the cabinets used would require to be of comparable strength to the reproducers, and the assistance of the specialist who constructed the metal cone loudspeaker assemblies was sought to manufacture four sheet-steel column-loaded units, of a suitable type to take the 23in × 14in elliptical wide-band speakers. These are situated at the four corners of the listening room and the opposite units are connected in parallel but in antiphase. This has the effect of increasing the apparent dimensions of the listening room, in addition to reducing the I^2R losses in the speaker wires.

Each unit is rated at 500W, with a nominal 20 Ω impedance. The required output from the amplifier is therefore 10A at 100V r.m.s. (282 volts pk-pk) per channel.

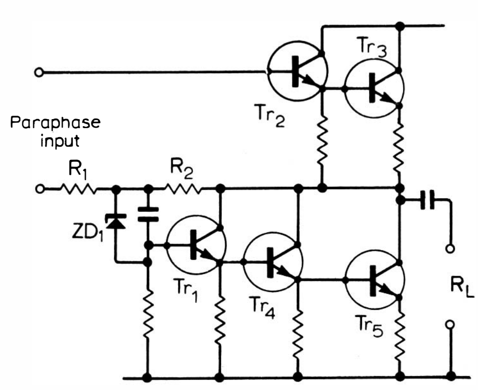

Fig. 1. Symmetrical output stage using only n-p-n transistors.

Power amplifier design

The use of a solid-state, transformerless amplifier to provide an output of 1kW into a 10-Ω load imposes certain limitations on the designer. In particular, the normal complementary or quasi-complementary output stage configurations are no longer practicable since the only useful and relatively cheap high-voltage transistors which are available are all of the n-p-n construction.

The basic output stage configuration employed, to provide a fully symmetrical push-pull class B output stage using only n-p-n transistors, is shown in Fig. 1. As shown, this would be satisfactory for power outputs up to about 50W.

In this circuit arrangement, Tr_2/Tr_3 and Tr_4/Tr_5 are Darlington pairs with Tr_2 and Tr_4 being normal small-power driver transistors. Tr_1, in combination with R_1 and R_2, provides the necessary signal level and amplitude transformation for the lower half of the output stage, and ZD_1 effectively stabilizes the voltage level at the power output point. This is chosen so that the largest symmetrical voltage swing is obtainable. The symmetry of this stage is maintained up to a frequency determined by the resistance of R_1 and R_2 and the input shunt capacitance of Tr_1. This will normally be well above the audible spectrum.

The final circuit employed is shown in Fig. 2. Although for simplicity only four parallel-connected output transistors are shown in each half of the output stage, this is only adequate for intermittent use at 1kW output. In practice six parallel connected transistors are required in each half of the output stage.

The paraphase input is obtained from two medium-power high-voltage transistors, Tr_3 and Tr_4, the h.t. supply for which is obtained from a separately smoothed 400-V line, because bootstrapping is not practicable with this type of driver stage.

The input is derived from a long-tailed pair of p-n-p transistors, of a type chosen for high voltage linearity, and freedom from avalanche or collector leakage (Early effect) distortion. Although 150V is applied to the end of the 'tail', the maximum collector-emitter voltage is limited to about 52V, because the base of Tr_2 is returned to the 50V tap on the zener diode chain. A variable resistor is included in the 'tail' to set the current through Tr_1 and Tr_2. This controls the current through Tr_3 and Tr_4, and, since the output d.c. level is determined by ZD_1, thereby controls the

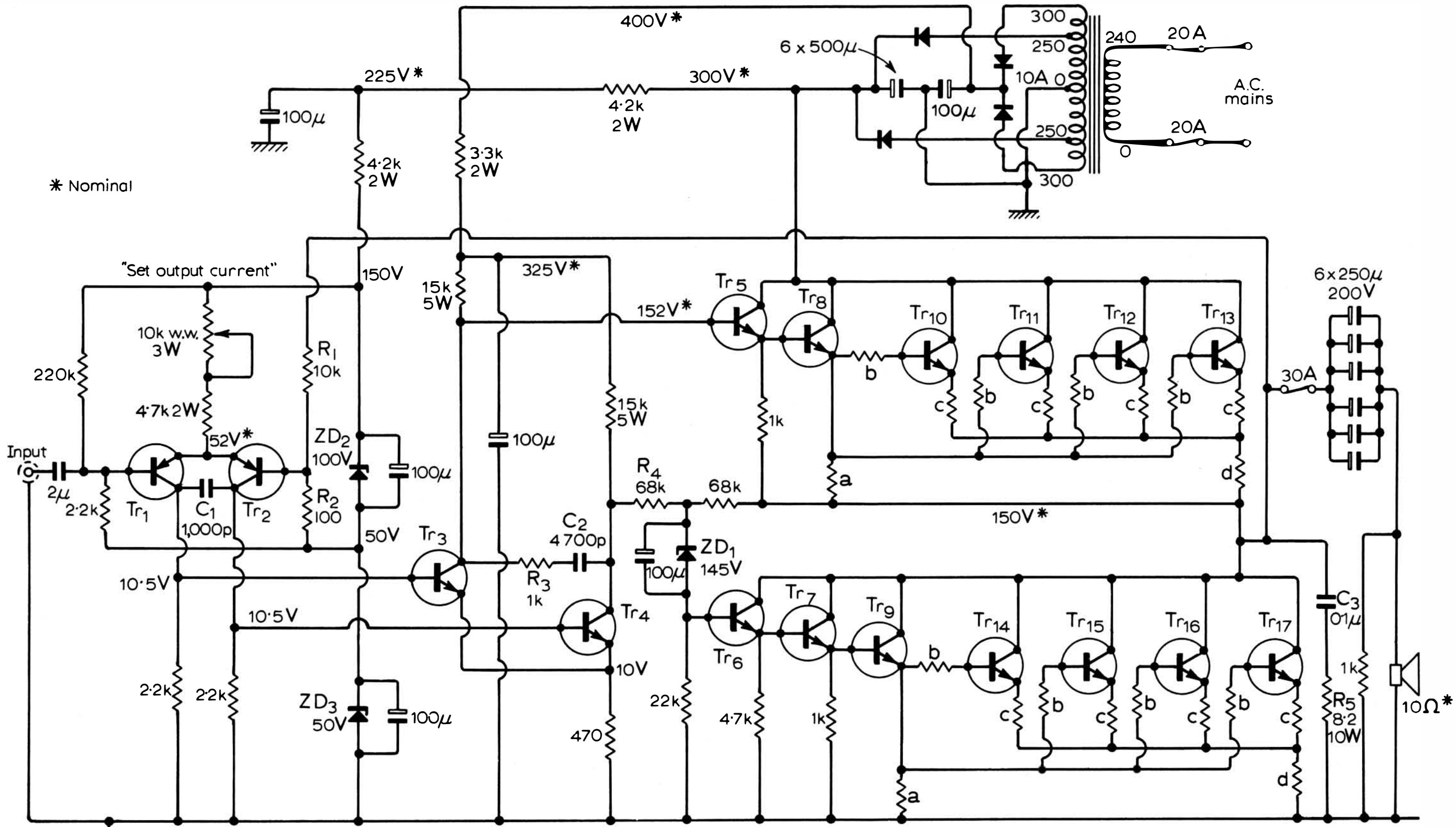

Fig. 2. Expanded version of Fig. 1 employing a Darlington triple as the output device. Tr_1, Tr_2—R.C.A. 38496; Tr_3 to Tr_7—MJE340; Tr_8 to Tr_{17}—MJ413. Lettered resistor values: a=22Ω, 2W; b=10Ω, 2W; c=0.5Ω, 5W; and d=0.1Ω, 5W.

quiescent current of the output stage. This should be set to about 200mA. Because of the absence of coupling or bootstrapping capacitors the gain of the circuit from the base of Tr_1 to the output of the power transistors is constant from the h.f. roll-off point down to d.c. The l.f. roll-off point is therefore determined solely by the 2-μF input capacitor and the output time constant.

The input impedance is 2kΩ in series with 2μF. The h.f. roll-off point and the phase stability margin is determined by C_1, (the input-lag capacitor) C_2 and R_3, and C_3 and R_5. The loop gain is determined by resistors R_1 and R_2 and is approximately 100. The full output is given by an input of 1V r.m.s., which can be obtained from any suitable high-quality pre-amplifier capable of operating into a 2-kΩ load.

Constructional details

The construction of the power amplifier unit follows conventional lines, and no unusual precautions are required apart from the need for generous heat sinks. Very satisfactory results were given in the prototype by the use of a pair of old cast-iron radiators, such as can be found second-hand for a few pounds in a builder's yard, to which the transistors can be individually attached by small bridges made from a suitably substantial gauge of copper sheet. The bottom and sides of an old copper preserving pan would be ideal. Care should, of course, be taken in drilling the attachment holes to make sure that the radiator shell is still capable of retaining water without leakage.

If such radiators cannot be found, a copper hot-water storage cylinder would serve admirably, but it would probably be more difficult to introduce such an item inconspicuously into the listening room. The siting of the output transistors should combine shortness of signal leads with the required thermal separation of the power transistors one from another. It should also be borne in mind that the circulating currents at full power are of the order of 30A. The leads to the loudspeaker terminal bosses—for which old car battery connectors are suggested—to the collector and emitter rails of the output transistors, and to the h.t. and earthy ends of the h.t. decoupling capacitor block must be substantial. A $\frac{3}{8}$in × $\frac{1}{4}$in bore copper pipe is preferable, but as an alternative, lengths of 12 s.w.g. copper wire may be plaited together.

After assembly, it is recommended that the amplifier units be bench-tested on a dummy load before attachment to the speaker units, since quite trifling faults can lead to a surprising amount of energy being released. For example, in preliminary listening trials with the prototype, an intermittent o/c in the earth braiding on an input to the pre-amp, led to the necessity for the listening room ceiling to be substantially restored and replastered.

Listening arrangements

Although the results obtained with good quality gramophone recordings have been most astonishing, and have brought home to the author in the most vivid way the qualities of stamina and emotional detachment required of an instrumental player situated, as the fortunate listener, in the midst of a large orchestra, it is clear that there are a large number of residual problems in the life-like reproduction of disc recordings, of which the major one is the avoidance of acoustic feedback. As with many other of these problems, it is suspected that the manufacturers of the equipment have not really got down to serious thought on this matter, and the solution which the author feels most people must adopt, that of housing the record player unit is some detached building, such as a small garden shed, is inconvenient and prevents the listener from hearing the beginning of the recorded piece. Moreover, if in one's hurry to return to the audition room, the pickup cartridge is let fall too rapidly upon the record, extensive damage can be caused to windows and other glazing.

Summing up

The performance of the equipment as installed is entirely satisfactory, and a wide variety of sound sources have been explored during the assessment of the scope of this system, and many sounds have been recaptured with a degree of realism not previously encountered. However, the development of this apparatus has not been without difficulty, scepticism and expense, and it has been suspected at times that unnecessary difficulties have been placed in the author's way. For these reasons, it is thought unlikely to appeal to those for whom high-fidelity reproduction is merely a passing interest. On the other hand, it has proved possible to purchase several of the adjoining properties at a very advantageous price, and this has undoubtedly offset a large part of the constructional costs.