Wideband audio power amplifiers

Ideas for class A designs with no overall feedback

by Y. Miloslavskij, Dipl. Ing. Institute of Constructional Physics, Moscow

Author suggests ideas for a wideband class A power amplifier (2-10 watts) without overall feedback using single-ended and/or push-pull circuits for his efficient loudspeakers and passive linear-phase filters with 6dB/octave slope. Input transistor is carefully selected for good linearity and Darlington pairs selected using a curve tracer. 10-20% instability in operating current can either be tolerated or reduced using thermistor biasing.

Nowadays it is not enough to possess only a good frequency response within an audio band; it is necessary to achieve more accurate reproduction of transients for which one needs extremely broad-band systems. In many cases, the importance of accurate reproduction of transients in music reproduction can be explained by considering the sound reproduction process and the specific characteristics of individual musical instruments, as pointed out and explained, for example, in "The Physics of Musical Sounds" by C. A. Taylor. There are many serious problems, which can hardly be solved in complete form in audio monitors because of the presence of several loudspeakers and accompanying filters.

Use of one radiator within the audio band is out of the question because of intense intermodulation, because of an increase in radiation directivity with increase in frequency, and because of conflicting design requirements of the radiator within the low and high frequency ranges. Direct-cut recordings can eliminate the imperfections of tape recordings, provided great attention is paid to the quality of other units. But such recordings are not often possible.

But it is a more unpleasant thing if serious problems arise within preamplifiers and power amplifiers. And so we face the problem: what if we use broad-band amplifiers both as audio preamplifiers[1] and as audio power amplifiers? This article suggests single-cycle and push-pull versions of a broad-band power amplifier with a maximum power output of 10W. Such output power is quite enough to create a sound pressure level within the peaks of 100 to 108dB inside a room with the volume of 30 to 120m^3 with high-output loudspeakers. Studies made in different countries show that such a level of sound pressure is plenty even for prolonged listening. This level of sound pressure is about the same as the peak levels in concert halls while listening to symphonic music somewhere in the centre of the pits at the fortissimo. Upper frequency limit of amplification of such amplifiers may be 20MHz and more[2].

Low frequency limit of amplification in the amplifiers depends only on the value of isolating capacitors. The output stages operate as emitter followers in class A. This helps to get low non-linear distortion, low output resistance and acceptable efficiency without negative feedback. Non-linear distortion of the emitter follower depends primarily on the ratio between resistor R_3 and the input resistance of the emitter follower, as well as on transistor linearity. The smaller the ratio, the lower the distortion. Also, the smaller the ratio, the lesser is the shunting effect of R_3 and the efficiency becomes greater, especially in the push-pull version. In the push-pull version of Fig. 1, to reach the best linearity it is necessary to achieve maximum symmetry of arms.

Fig. 1. Example of push-pull class A amplifier without external feedback used in author's l.f. loudspeaker channel. Output transistors have a $V_{ce(max)}$ of 120 to 400V, $I_{c(max)}$ of 8 to 12A, $P_{c(max)}$ of 50 to 120W, f_T of 3 to 20MHz and an heat dissipator of 1200 to 1800cm^2. Darlington pair: current gain 5000 to 10,000, output device 60 to 90.

Maximum value of non-linear distortion is 0.1 to 0.2%. Non-linear distortion of the amplifiers is also determined by linearity of transistor Tr_1 and the local negative feedback of this stage. It is a good idea to choose the transistors, especially the complementary pairs, with an accurate curve tracer. At the same time, it is possible to estimate the value of current gain (β), V_{min}, I_{min}, linearity, and the important dependence $\beta = \beta(I, V, T^o)$. Output resistance in these cases is determined mainly by the following ratios:

$$R_3/\beta_{Tr2} \times \beta_{Tr3} \text{ and } R_3/\beta_{Tr4} \times \beta_{Tr5}$$

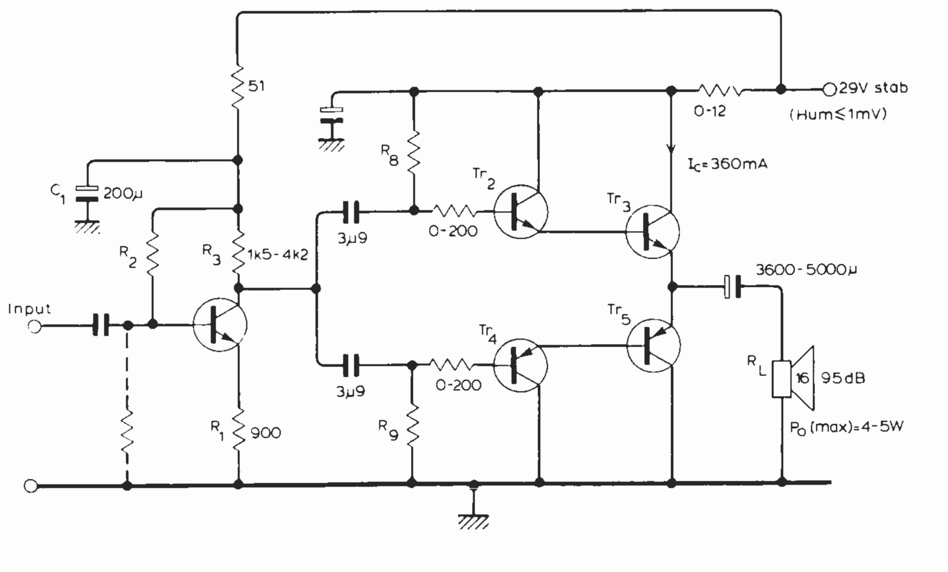
For horn loudspeakers with high outputs exceeding 105 to 108dB (1m, 1W) one may use the single-cycle circuit of the power amplifier, Fig. 2, for outputs of 0.5 to 2W (and even for an l.f. power amplification channel up to 4 to 5W). Efficiency of such a circuit is 4 to 5%. Maximum efficiency for the circuit on a sinusoidal signal is approximately 8.7% (reference 2) at $R_6 = 1.41R_L$. The basic formulae are

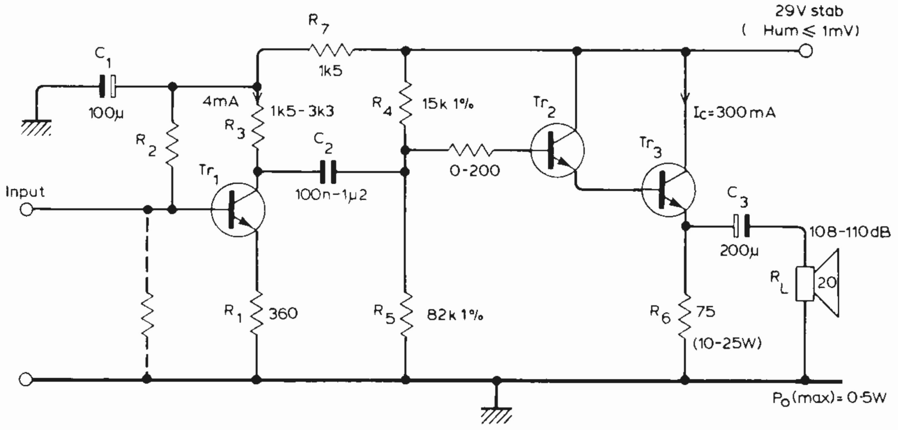
$$I_{C(out)} \approx 2.41\sqrt{P_{out(max)}/R_L} + I_{min}$$

$$V \approx 4.83\sqrt{P_{out(max)}R_L} + V_{min} + I_{min}R_6 + V_{BE(Tr3)}$$

In the given circuit the resistor $R_6 =$ 3 to $6R_L$ ($R_L = 15\text{-}20$ ohm) which leads to decreasing the power dissipated in Tr_3 and allows the amplifier to be fed from the voltage source for the l.f. power channel.

Temperature of the transistor junctions must not exceed 70-80°C. Ignoring





this condition may lead to the increase of the coefficient α_2 to α_n of the transfer characteristics and will worsen the stability of the operating current of the transistors. The instability of operating current (with a sufficiently high current running through the R_4/R_5 bias chain) is approximately 1mA. The circuit needs no adjustment, except for preliminary circuit calculations and selection of components with the required parameters. Subjectively, such a single-ended amplifier sounds no worse than the push-pull one.

The required operating current is obtained automatically. Calculation of the operating current value and of R_6 depends on the maximum output power and power supply voltage, and is not given here. Rearranging the formulae

$$I_{C(out)} \approx 1.1 \text{ to } 1.2 \frac{\sqrt{2}\sqrt{R_4 \cdot P_{out(max)}}}{\frac{R_L R_6}{R_L + R_6}}$$

$$V_{CE(Tr3)} \geq N2\sqrt{R_L \cdot P_{out(max)}} + V_{min(Tr2,3)} + 0.8V$$

For good symmetry of arms of the push-pull stage, $R_9 \approx R_8$ and

$$\beta_{Tr3} \times \beta_{Tr2} \approx \beta_{Tr4} \times \beta_{Tr5}$$

and preferably $\beta_{Tr3} \approx \beta_{Tr5}$.

Instability of the output current has the same quality as the current in the power amplifier by J. L. Linsley-Hood[3]. It is desirable that the Tr_1 to Tr_5 transistors should be high-voltage ($V_{c(max)}$ 100 to 400V) and with optimum current margins. As a rule, this improves linearity.

Generally from the point of view of quality, total cost and total efficiency the combination of a 1W power amplifier plus high-output horn loudspeaker seems more rational than the choice of almost kilowatt power amplifier plus loudspeakers with 80 to 88dB (1m, 1W) output. For the last-mentioned case it is essentially more difficult to build a high quality power amplifier. Moreover, the problem of heat drainage from the loudspeaker voice coil arises as well as the problem of steady and stable loudspeaker performance, not to mention distortion. Let R_6 be heated, for its heating influences absolutely nothing!

For an l.f. power amplifying channel with a loudspeaker output of 94-97dB

Fig. 2. Single-ended version of m.f. and h.f. horn loudspeaker channels uses 2 to 5A output transistors with $V_{ce(max)}$ of 300 to 500V and $P_{c(max)}$ of 25 to 50W. Heat sink 150 to 300cm^2. Darlington pair gain 3,000 to 5,000. Input transistors have $V_{ce(max)}$ of 120 to 300V, $I_{c(max)}$ 0.5 to 1A, f_T 20 to 50MHz, $P_{c(max)}$ 0.6 to 1.5W and current gain 70 to 140. Capacitors C_2, C_3 have been chosen to attenuate l.f. gain.

(1m, 1W) it is possible to employ the push-pull version for an output of 4 to 10W. The maximum coefficient of performance of such a circuit is somewhat less than 50%. Basic formulae for calculation are

$$I_{C(out)} = \sqrt{P_{out(max)}/2R_L} + I_{min}$$

$$V = 2(\sqrt{2P_{out(max)}R_L} + V_{min} + V_{BE(Tr5)})$$

if $V_{BE(Tr5)} = V_{BE(Tr3)}$, $V_{min(Tr2,3)} = V_{min(Tr4,5)}$.

The instability of $I_{C(out)}$ can be reduced if necessary with the help of thermistors, used instead of R_8 and R_9. Values should be calculated or experimentally chosen, and the thermistors must have a positive temperature coefficient.

Each arm of the amplifier is "trimmed" separately. Choose R_2 so that symmetrical clipping of the sinusoid is reached after applying voltage to the circuit for 15 to 20 minutes. Further, using half the value of the calculated supply voltage, the value of current $I \approx 0.9 I_{c(out)}$ is set (using the initial ammeter reading) in the complementary Darlington pairs by adjustment of resistors R_8 and R_9; then the arms are connected.

This circuitry is adopted as the basis for a three-way power amplifier (0.5 to 10W) with passive (phase-linear) filters having 6dB/octave steepness at the power amplifier input. Capacitors C_2, C_3 serve also to attenuate low frequencies in the m.f. and h.f. power channels. □

References

1. Miloslavskij, Y. Audio preamplifier with no t.i.d. *Wireless World*, vol. 85, August 1979, pp. 58-60.

2. Cykin, G. S. Sherokopslassiy Kaskaly Moshnogo Usilenja (Broad-band stages of powerful amplification) *Radiotechnica*, no. 5, 1968.

3. Linsley-Hood, J. L. Simple class A amplifier, *Wireless World*, vol. 75, 1969, p. 148 (see also correction & correspondence).

Literature Received

"How to become a radio amateur" is, as its title suggests, a set of regulations and licensing conditions for those wishing to take up the hobby. It contains information on frequency bands, types of transmission and a syllabus of the examination, with all necessary addresses. The booklet can be obtained free from the Home Office, Radio Regulatory Department, Radio Regulatory Division, Licensing Branch (Amateur), Waterloo Bridge House, Waterloo Road, SE1 7UA. WW 401

Data sheets on the Telrex range (900 models) of aerials, aerial arrays, masts and rotators can be obtained from Telrex Laboratories, Asbury Park, 07712 New Jersey, USA. WW 402

An application note dealing with theoretical and practical aspects of **charging high-voltage capacitors** (resistive, constant-current and constant-power) forms one of a series, available from Hartley Measurements Ltd, Kenwood House, Hartley Wintney, Basingstoke, Hampshire. WW 403

Fibre-optic cables, connectors, receivers and transmitters made by Suhner are described in a brochure entitled 'Fibreoptic', which is obtainable from Suhner Electronics Ltd, Telford Road, Bicester, Oxon, OX6 OLA. WW 404

A catalogue of **home computers,** peripherals and accessories is produced by Microdigital, 25 Brunswick Street, Liverpool L2 OP1. The company runs a hiring system in addition to its sales operation. WW 405

IMS is the **Industrial Microcomputer System** developed by Mullard. It uses Signetics 2650 microprocessors and is associated with Modest, a development system. The whole system is modular in form, avoiding too-complex or too-simple solutions to specific problems. A booklet on IMS can be obtained from Central Enquiry Handling Unit, Tech. Publications Dept, Mullard Mitcham, New Road, Mitcham, Surrey CR4 4XY. WW 406

A booklet on the range of **r.f. power** meters and dummy loads, working in the frequency range 2-1000-MHz, manufactured by Dielectric Communications, is obtainable from the UK representative, Tony Chapman Electronics Ltd, 80a, High Street, Epping, Essex CM16 4AE. WW 407

The first of a range of digital **transit recorders,** Model VK-22, which has a 2K × 8-bit memory, has been announced by Prosser, who can supply a descriptive leaflet. Prosser Scientific Instruments Ltd, Lane Lane Industrial Estate, Hadleigh, Ipswich, IP7 5DQ. WW 408

Power supply modules for X-ray image intensifiers are described in a leaflet, available from Brandenburg Ltd, 939 London Road, Thornton Heath, Surrey CR4 6JE. WW 409

Switches of various types for printed-board mounting are marketed by Waycom, who have a brochure "EECO PCB Switches", which can be had from Waycom Ltd, Wokingham Road, Bracknell, Berks RG12 1ND. WW 410

Guides to the selection and use of Scotchcast **liquid resin** (potting resins) and Scotch electrical tapes are obtainable from 3M, PO Box 38, Yeoman House, 57-63 Croydon Road, London S.E.20 7TR. WW 411