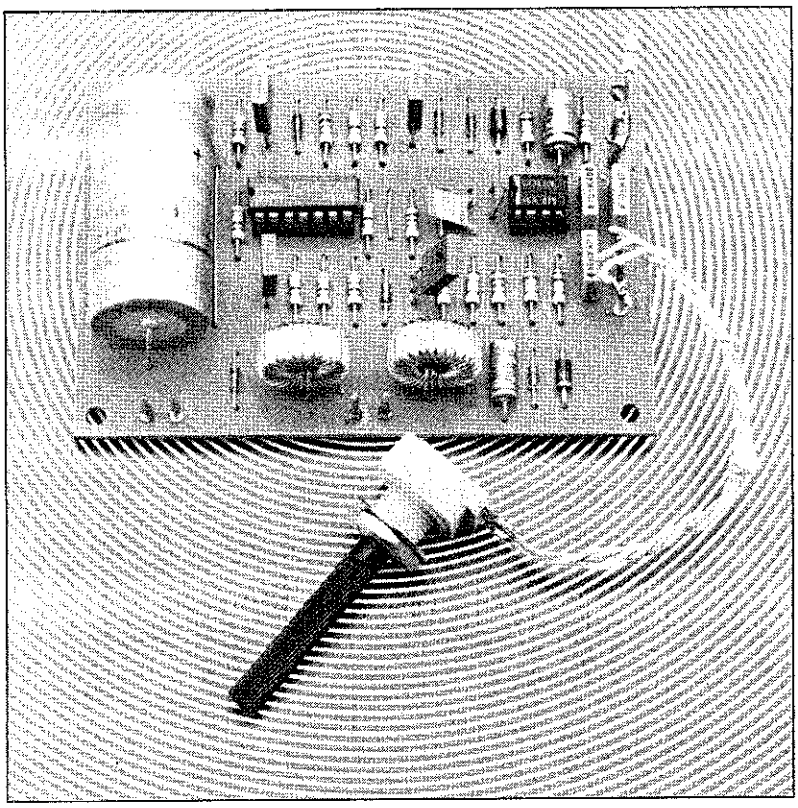
CLASS-D AMPLIFIER

by J. Bareford

The terms digital amplifier, class-D amplifier, switched amplifier and PWM amplifier all refer to a type of amplifier that converts its input signal into a rectangular signal with variable duty factor. The high efficiency achieved by a class-D amplifier makes it of particular interest for mobile and public address applications, where low distortion is not a prime issue. The AF power amplifier described here works from a 6 V battery, and delivers up to 5 watts. A such, it is eminent for use in, for instance, a megaphone.

A well-known problem with mobile AF amplifiers is that their low efficiency makes it virtually impossible to generate high power levels from a low supply voltage. The amplifier described here has a total efficiency of almost 100% at a distortion level that is tolerable with megaphones and similar P.A. equipment. The basic principle behind the design is



Pulse-width modulation

Figure 1 shows the principle of pulse-width modulation (PWM): the input signal controls the duty factor of a rectangular signal of a much higher frequency. The on-time of the pulse is proportional to the instantaneous amplitude of the input signal. The sum of the on-time and the off-time — and, therefore the frequency — is, however, constant. Hence, a symmetrical rectangular signal (square wave) is generated in the absence of an input signal.

In order to obtain reasonable sound quality, the frequency of the rectangular wave must be at least twice as high as the highest frequency in the input signal. A simple low-pass filter may then be used for integrating the rectangular signal. The result is a signal that may be used for driving a loudspeaker. The signal conversion is apparent from the lower oscilloscope trace in Fig 4. The upper trace displays the output signal after filtering, measured across the loudspeaker. The amplitude of the residual PWM signal superimposed on the sinewave is small.

Switches as amplifiers

The basic operation of the PWM amplifier may be illustrated with the aid of the block diagram in Fig. 2. Assuming that the input is short-circuited, switch S_a charges capacitor C_7 with a current I_2, until a voltage is reached that corresponds to the upper switching threshold of the electronic switch. This then connects R_7 to ground. Next, C_7 is discharged to the lower switching threshold of S_a. The resulting square wave has a frequency of about 50 kHz, as determined by C_7 and R_7.

An AF signal applied to the input of the amplifier effectively causes the additional current I_1 to proportionally reduce or increase the charge time, and increase or reduce the discharge time. The input signal thus controls (*modulates*) the duty factor of the rectangular signal which appears at the loudspeaker output.

Two further principles are important for the basic operation of the PWM amplifier. First, switch S_b is controlled in anti-phase with S_a, and keeps the other loudspeaker terminal at a voltage complementary to that of the PWM signal. This arrangement results in a switching power output stage of the bridge type: the loudspeaker is driven with the full supply voltage at each polarity, so that the highest possible current consumption is achieved.

The second additional point to note concerns inductors L_1 and L_2. These integrate the rectangular signal and so make it sinusoidal as seen in Fig. 4. The inductors also serve to suppress harmonics of the 50 kHz rectangular signal.

High sound levels from a small circuit

The components shown in the block diagram are easily recognized in the circuit diagram of Fig. 3. The input section of the PWM amplifier is formed by a capacitor (or electrostatic) microphone, biased via R_1, coupling capacitors C_1 and C_4, a volume control, P_1, and an

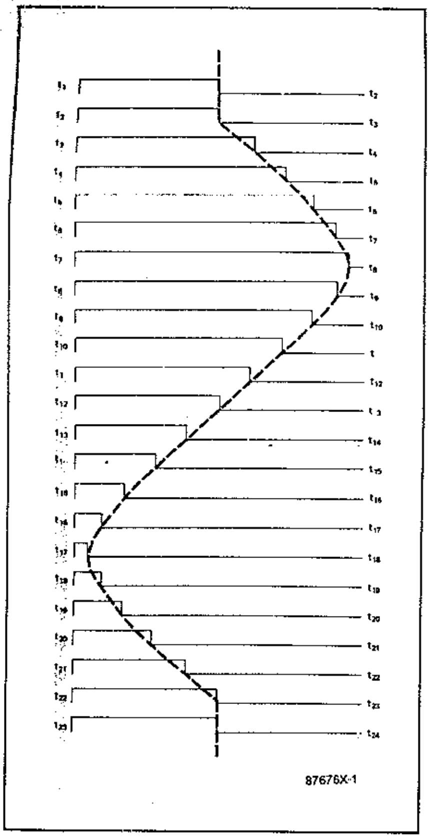


Fig. 1. Conversion of a sine-wave into a pulse-width modulated (PWM) signal.

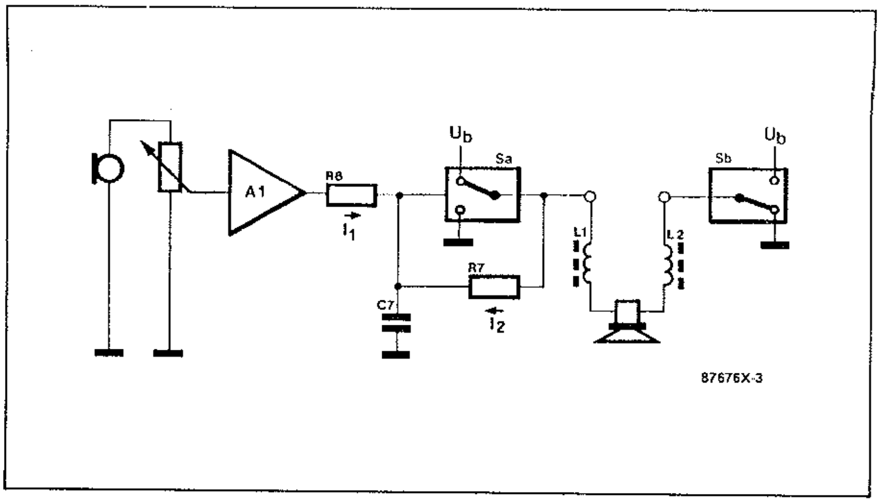


Fig. 2. Block diagram of the class-D amplifier.

amplifier based around opamp A_1. The previously discussed switches S_a and S_b are formed by electronic switches ES_1 to ES_4 in combination with transistor pairs T_1-T_3 and T_2-T_4. The part indications for the components that form the PWM generator correspond to those discussed with the block diagram.

The unusually high efficiency of the PWM amplifier is perhaps best illustrated by the fact that the output transistors remain cool under all drive conditions — dissipation in the power output stage is virtually nought.

When selecting practical inductors for L_1 and L_2, remember that their ability to pass 3 A without becoming saturated is far more important than the actual inductance. The inductors used in the prototype were toroid types salvaged from a lamp dimmer.

Diodes D_3 to D_6 limit the reverse e.m.f. generated by the inductors to a safe

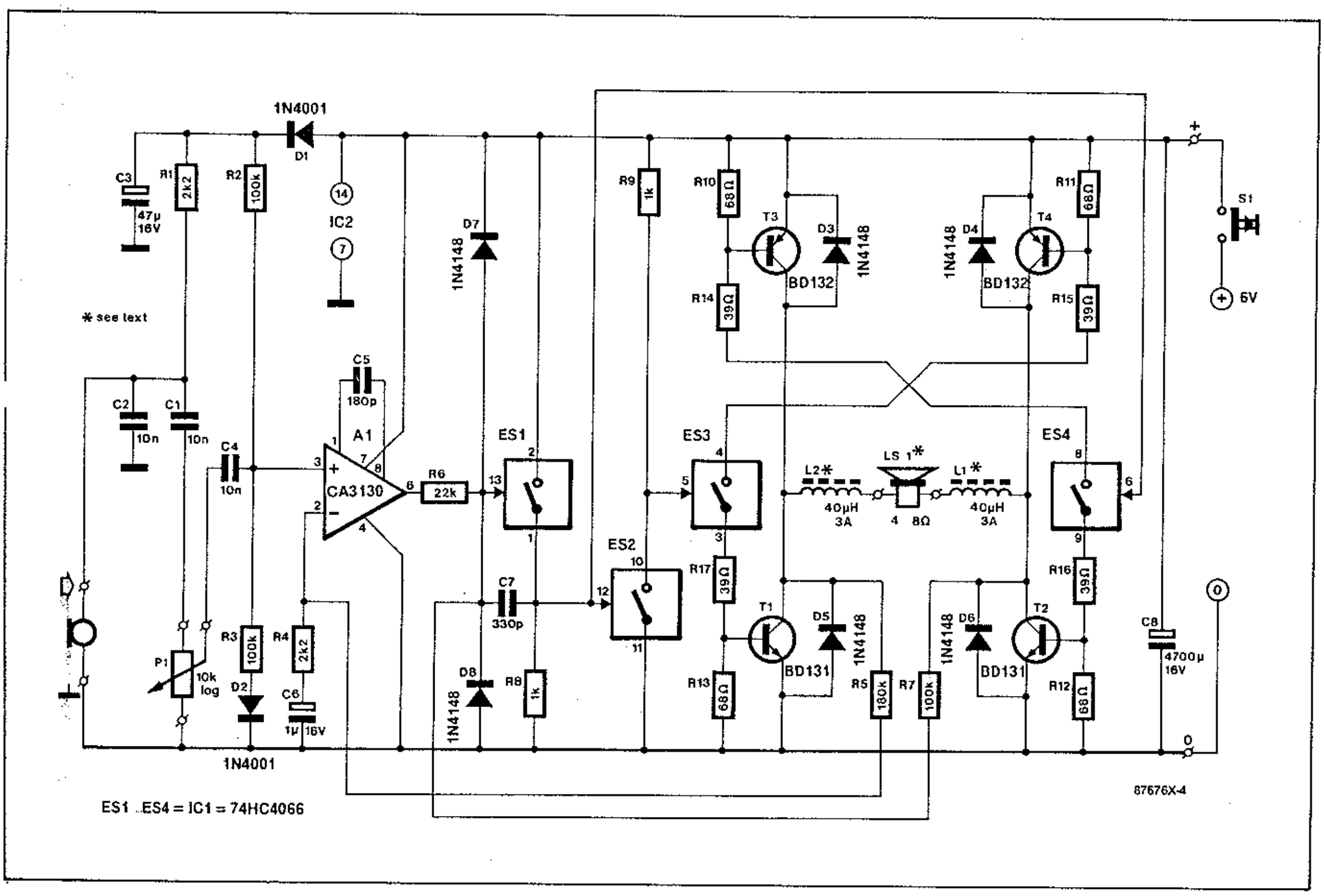


Fig. 3. Circuit diagram of the 4 W class-D amplifier for public address applications.

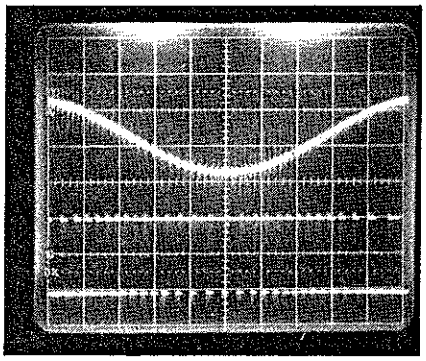


Fig. 4. Sinusoidal output signal (upper trace) and PWM control signal (lower trace).

value Components D_1, C_3, D_2 and R_3 provide the non-inverting input of opamp A_1 with a well-filtered potential equal to half the supply voltage. As with a conventional opamp-based amplifier, the voltage gain is set by a negative feedback network. In practice, R_4 and R_5 set the gain to 83 to ensure adequate microphone sensitivity. When high-impedance signal sources are used, R_4 may be increased accordingly.

Because of the phase shift introduced by L_1 and L_2, feedback is realized with the aid of the rectangular signal at the collector of T_1, rather than with the sinusoidal loudspeaker signal. The opamp itself, in combination with C_5, provides the required integration of the PWM feedback signal. It should be noted that the feedback system reduces the amplifier's distortion, but not, unfortunately, to a level that would make it suitable for applications other than public address. A class-D amplifier with low distortion would require a much higher supply voltage than used here, and would be a fairly complex design. This, in turn, would almost inevitably result in much reduced overall efficiency. The electronic switches in the amplifier must be HCMOS types — a standard CMOS Type 4066 is so slow as to cause a short-circuit across T_1-T_3 and T_2-T_4, with the obvious risk of overloading or even destroying the amplifier.

Bullhorn

The class-D amplifier is preferably used for driving horn-type loudspeakers, since these offer the highest sound pressure for a given power level. The prototype of the amplifier was used in combination with a 6 V battery pack and a pressure chamber loudspeaker. The available 4 watts of output power resulted in a megaphone with an impressive acoustic range.

Four series-connected 1.5 V dry batteries (HP11; C; UM2; Baby) or alkaline monocells provide the supply voltage for the megaphone. When this is used frequently, a rechargeable NiCd or gel-type (Dryfit) battery may be preferred. The maximum current consumption of the megaphone is about 0.7 A, so that an alkaline battery has sufficient capacity for 24 hours operation at full output power. For non-continuous operation, however, a set of dry batteries is perfectly adequate.

Whatever power source is used, the supply voltage for the amplifier should not exceed 7 V, because the HCMOS switches in IC_1 do not operate correctly any more at this level. Fortunately, the absolute maximum supply level for the amplifier is higher at 11 V.

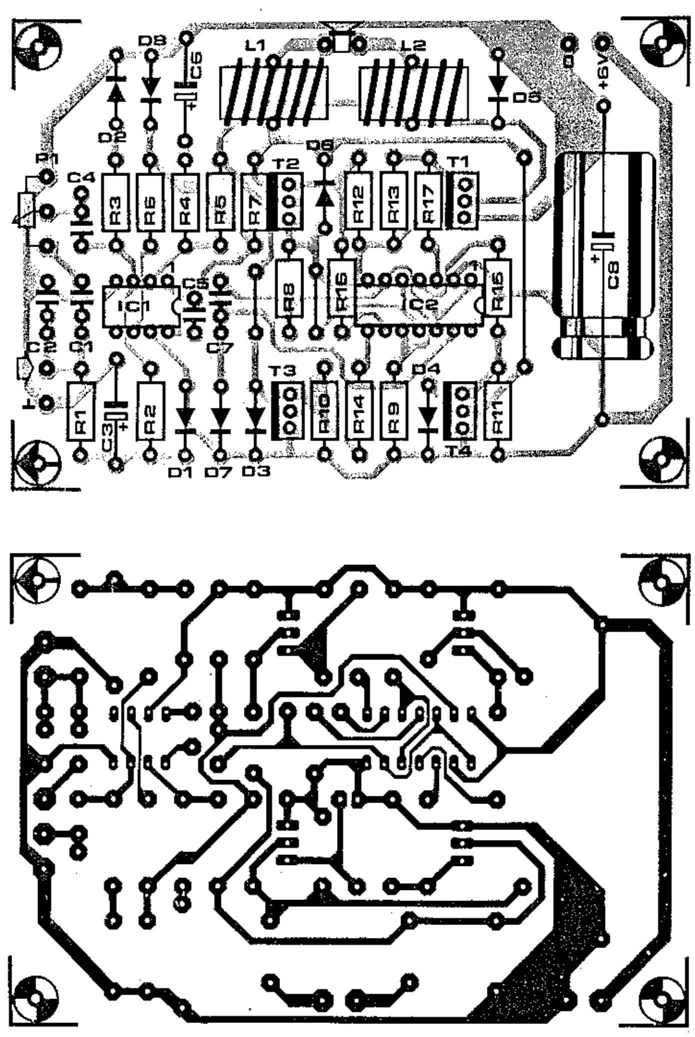


Fig 5. Printed-circuit board for the amplifier.

Parts list

Resistors (±5%):
- R_1;R_4 = 2K2
- R_2;R_3;R_7 = 100K
- R_5 = 180K
- R_6 = 22K
- R_8;R_9 = 1K0
- R_{10} ... R_{13} incl. = 68R
- R_{14} ... R_{17} incl. = 39R
- P_1 = 10K logarithmic potentiometer

Capacitors:
- C_1;C_2;C_4 = 10n
- C_3 = 47μ; 16 V
- C_5 = 180p
- C_6 = 1μ0; 16 V
- C_7 = 330p
- C_8 = 4700μ; 16 V

Semiconductors:
- D_1;D_2 = 1N4001
- D_3 ... D_8 incl. = 1N4148
- T_1;T_2 = BD131 or BD226
- T_3;T_4 = BD132 or BD227
- IC_1 = CA3130
- IC_2 = 74HC4066

Miscellaneous:
- S_1 = push-to-talk switch.
- L_1;L_2 = 40μH; 3 A toroid suppressor choke.
- LS_1 = 4 ... 8R; 10 W; waterproof horn loudspeaker.
- Capacitor microphone.
- PCB Type 87676 (not available through the Readers Services)