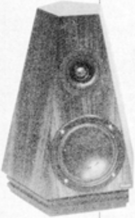
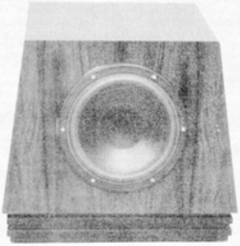
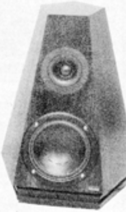
*The subwoofer described in this article can be used to extend any existing loudspeaker system. It has been designed to obtain a frequency response within ±1 dB over the frequency range 30-100 Hz with an enclosure volume of only 85 litres.*







# ACTIVE SUBWOOFER

The faithful reproduction of very low audio frequencies in normal living rooms poses a number of problems. The first is that the lowest frequency, $f$, that can be reproduced depends on the length, $l$, of the room:

$$f = c/2l \text{ [Hz]}$$

where $c$ is the velocity of sound waves in metres per second at normal atmospheric pressure and at 20 °C.

In a 6-metre long room, therefore, the lowest frequency that can be reproduced without distortion is about 28 Hz. In practice, other problems, such as the vibrating of doors, windows, cupboards, glassware, and so on, become evident long before this frequency has been reached.

A more important problem concerns the dimensions of the enclosure. For a reasonably faithful reproduction at 30 Hz and full volume, the enclosure should normally have a volume of not less than 100 litres, and preferably about 200 litres. Two such large boxes required for a stereo installation are often unacceptable in a normal living room.

Fortunately, there is an alternative which offers much the same bass performance and has a much more modest space requirement. It uses only one enclosure for the low frequencies, even in stereo operation. For the middle and high frequencies, one loudspeaker system per channel remains required.

The alternative solution is made possible by the human ear having virtually no sense of direction at frequencies below about 200 Hz. This means that if frequencies below, say, 100 Hz, are reproduced by one central subwoofer, and the remainder of the audio spectrum by so-called satellite loudspeakers, there is no discernible impairment of the stereo effect. Note that the satellite speakers can be kept small

**Technical characteristics**

| | |
|---|---|
| System: | active closed box |
| Net volume: | 85 litres |
| Crossover network: | electronic; 24 dB/octave; Bessel filter |
| Frequency range: | 30-100 Hz (see Fig. 1b) |
| Recommended amplifier output: | 50-100 W |
| Maximum sound pressure: | >100 dB (50-100 Hz) |
| Sensitivity: | 87.5 dB (1 watt at 1 metre) |

The system has been provided with a presettable output power limiter because they are required to reproduce frequencies above 100 Hz only. The design and construction of these satellite loudspeakers will be described in this issue.

Table 1 shows some types of loudspeaker system and their most important characteristics. It is clear that the closed box generally offers the best performance, were it not for its inability to reproduce very low audio frequencies when its volume is modest to small. The bass reflex and transmission-line types are superior in this respect, but these suffer from an inferior frequency response characteristic and a much worse step response. The horn and transmission-line types are, furthermore, rather difficult to build.

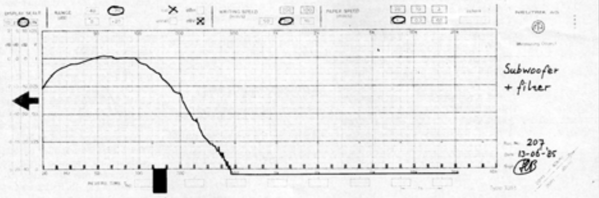
This leaves, in practical terms, the active closed box. The properties of this type depend to a large extent on its specific design, which can be approached from different directions. The questions that immediately crop up are: "how low should the −3 dB point be?", and "what are the acceptable dimensions of the enclosure?". The lower the frequency at the −3 dB point for a certain volume, or the smaller the dimensions for a given −3 dB point, the more electronic correction will be necessary.

*Table 1. Some prominent types of loudspeaker system and their most important properties.*

| Type of system | Dimensions | Sensitivity | Step response | Characteristic | Lower −3 dB point |
|---|---|---|---|---|---|
| Horn | very large | very high | reasonable | very irregular | fairly high |
| Bass reflex | large | high | reasonable | irregular | low |
| Transmission line | large | low | poor | irregular | low |
| Closed box | large | fair | good | tapering | high |
| Active closed box | small | reasonable* | good* | smooth* | low* |

* Depends to a large extent on the system set-up.

1a




1b


*Fig. 1a. Frequency response characteristic of the Dynaudio 30W54 drive unit in an 80-litre closed box without any filtering.*

*Fig. 1b. Frequency response characteristic of the Dynaudio 30W54 drive unit in an 80-litre closed box with electronic crossover network and correction filter.*

But this correcting cannot be taken too far, otherwise the sensitivity as well as the step response will suffer; also, distortion will increase and power handling will be reduced.
The present system was designed to give a reasonable performance without any electronic help first, and then some electronic circuits were added to extend the frequency range downwards.
The frequency response of the subwoofer in an 80 l enclosure is given in fig. 1: 1b clearly shows the effect of the added filters, particularly the lowering of the −3 dB point from about 50 Hz to 30 Hz.

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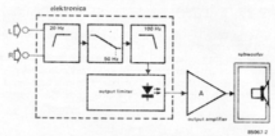



*Fig. 2. Block schematic of the active subwoofer system. Any good 50-100 W power amplifier may be used as output amplifier.*

## Set-up

The system is arranged as shown schematically in Fig. 2, and is seen to consist of the loudspeaker in its enclosure, an output amplifier, and an electronic circuit. The output amplifier will not be discussed here, because any good type may be used, as long as it is capable of delivering at least 50 W into 8 ohms.
The enclosure is simple to build as described under *Construction*. The loudspeaker used in the prototype was a Dynaudio (Denmark) type 30W54 —see Fig. 3. This is a robust 300 mm drive unit on a light metal frame with high peak power handling capability, good step response, and a suitable frequency response (see Fig. 1a).
The electronic circuit consists of two parts: the filters and the output limiter. There are three filters: a steep-skirted anti-rumble type with its change-over point at 20 Hz; a correction filter for the very low audio frequencies from 50 Hz downwards; and a crossover filter with change-over point at 100 Hz and a slope of 24 dB/octave. The combination of these filters results in the frequency response shown in Fig. 1b.
The output limiter is, strictly speaking, not essential but very useful, particularly where full volume is used habitually. It has been added to allow for the decreasing power handling capability of the drive unit below 50 Hz. The coming into operation of the limiter is indicated by the lighting of an LED.

## Subwoofer and satellite speakers

In principle, the subwoofer can be used as an addition to any loudspeaker system that has unsatisfactory performance at low frequencies. If, however, a new loudspeaker system is planned, the design of the satellite speakers should take account of the subwoofer. These units need reproduce frequencies above 100 Hz only, so that the volume of their enclosures can be kept to about 10 litres.

The various units should be interconnected as shown in Fig. 4. The simplest and least expensive way is shown in Fig. 4a: the subwoofer system, including the output amplifier and filters is simply connected to the loudspeaker terminals of the existing amplifier. Capacitors C form a 6 dB filter to protect the satellite speakers high low-frequency output power. The necessary level matching between the subwoofer and the satellite speakers may be effected with a preset on the filter PCB.
Where the pre-amplifier an output amplifier are separate units, interconnections may be made as illustrated in Fig. 4b. In this way, each loudspeaker has its own output amplifier, so that filtering can take place between the pre-amplifier and the output amplifiers. The set-up in Fig. 4b is preferable to that in Fig. 4a.
The question may be asked why the satellite speakers are filtered at only 6 dB/octave from 100 Hz, whereas the subwoofer has a skirt roll-off of 24 dB/octave. The answer is that the satellite speakers (in a closed box) have an inherent fall-off of about 12 dB/octave. Together with the additional filtering, this works out at 18 dB/octave, which is ample in this combination.
The value of capacitors C is determined from

$$C = 10^6/2\pi Z f_c \qquad [\mu F]$$

where $Z$ is either the impedance of the satellite speaker (Fig. 4a), or the

3


*Fig. 3. The Dynaudio 30W54 drive unit.*

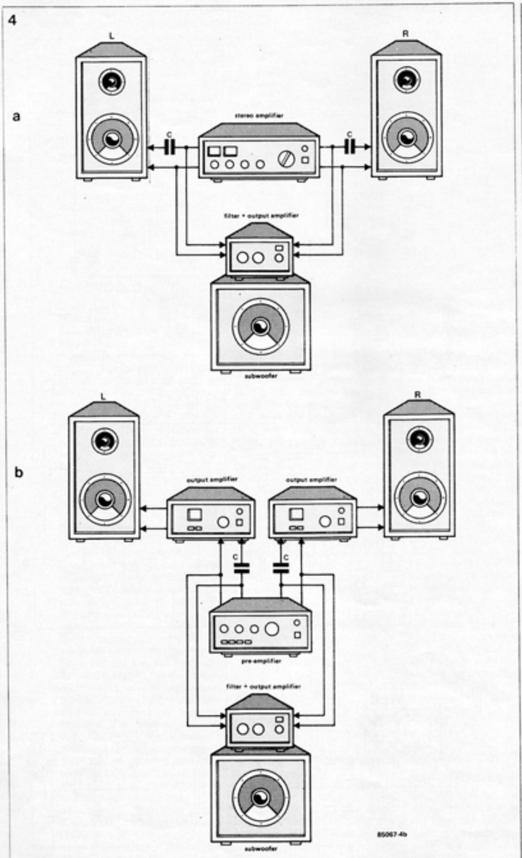



*Fig. 4. Two different arrangements for using the subwoofer system with a pair of satellite loudspeakers. The set-up in 4b is preferred.*

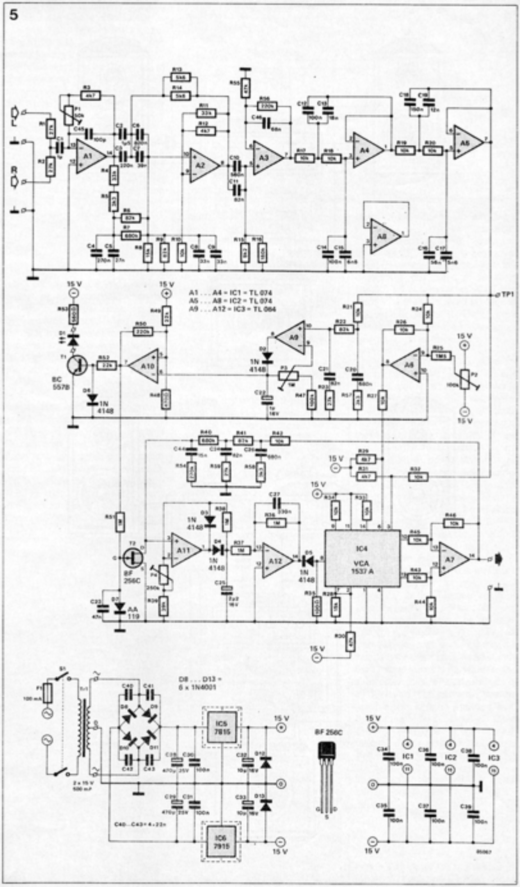
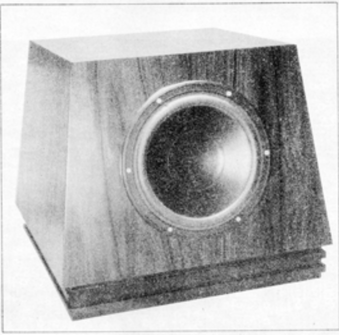



*Fig. 5. The circuit diagram of the three filters and output power limiter. Diode D1 should be mounted so that it can be seen from the outside, since it serves as overload indicator.*

input impedance of the relevant output amplifier (Fig. 4b) in ohms, and $f_r$ is the roll-off frequency in hertz.
If, therefore, in Fig. 4a the satellite speaker impedance is 8 ohms, and the roll-off frequency is 100 Hz, the series capacitor should have a value of 200 μF. It is recommended to shunt such large bipolar electrolytic capacitors by a foil capacitor of 1 μF, which improves the properties of the filter.
Since the input impedance of the output amplifiers in Fig. 4b is considerably higher than the loudspeaker impedance, the value of the filter capacitor is much smaller. For instance, an input impedance of, say, 20 k gives a value of C=80 nF (use 68 nF or 0.01 μF).



## Electronic circuits

The circuit diagram of the three filters and the active output limiter is given in Fig. 5.
After the two input signals have been summed in amplifier $A_1$, they are applied to a complex rumble filter formed by $A_2$. This elliptical or Cauer (high-pass) filter provides an attenuation of 0 dB at 25 Hz, −3 dB at 20 Hz, and 40 dB at 10 Hz. Note that some resistors and capacitors are connected in parallel to obviate the need for non-standard 1 per cent components.
The rumble filter is followed by the correction filter, which, covering a range of only 3-6 dB, is a fairly simple circuit. It is formed by $A_3$ and the frequency-determining components are $R_{56}$ and C46 .
The third filter is the actual crossover network and is constructed around $A_4$ and $A_5$. It is a fourth-order Bessel type which provides an even phase shift and very good step response.
The remainder of the circuit is the active output power limiter. The filtered signal at pin 7 of $A_5$ is applied to a metering circuit formed by $A_8$ and $A_{10}$. Network $R_{21}$-$R_{22}$-$R_{23}$-$R_{57}$-$C_{20}$-$C_{21}$ ensures that the input to $A_8$ is large at low frequencies (against which the system needs protection) and small at high frequencies. The rectified signal is compared in $A_{10}$ with a reference voltage. If the signal becomes too large, the comparator toggles, $T_1$ is switched on, and $D_1$ lights. At the same time, $T_2$ is switched off and the control loop of attenuator $IC_4$ is actuated.
The voltage-controlled attenuator (VCA) was described in *Design Ideas* in the February 1986 issue of *Elektor India*. Opamps $A_6$ and $A_7$ provide buffering of the input and output of the VCA respectively.

The buffered signal at pin 14 of $A_7$ is passed via low-pass filter $R_{40}$-$R_{41}$-$R_{42}$-$R_{54}$-$R_{58}$-$R_{59}$-$C_{24}$-$C_{26}$-$C_{44}$ to active rectifier $A_{11}$. This low-pass filter serves to adapt the control characteristics to the frequency-dependent power curve of the loudspeaker. Note that the signal is passed to $A_{11}$ only when T2 is switched off. The output of the rectifier is applied to the control input of the VCA via integrator $A_{12}$.
As long as the signal level at pin 6 of $A_{10}$ remains below that of the reference voltage at pin 5, $T_2$ remains on. The control loop of the attenuator is then inactive and the VCA merely passes all signals applied to it. This arrangement ensures effective limiting of the output signal.
The power supply is a fairly standard circuit. Diodes $D_{12}$ and $D_{13}$ prevent a temporary reversal of the supply voltages on switch-off: the ICs cannot then accidentally be put into an undefined state.

## Construction (electronic circuits)

It is best to complete the electronic part first on the PCB shown in Fig. 6. Most if this work is pretty straightforward, except for the heat sink of regulators $IC_5$ and $IC_6$. This should be made from a 25×100 mm strip of 1 mm thick tin or tinned copper. Bend this lengthwise into an L of 70×30 mm. Drill two holes in a suitable position in the short leg to receive the ICs. Place the heat sink onto the PCB along the indicated fat line and solder it in place with the aid of two pins mounted as shown. The regulators are then fitted to the heat sink: the 7815 without, and the 7915 with, insulating washers.
If the arrangement of Fig. 4b is used, the values of resistors $R_1$ and $R_2$ should be as shown in the parts list. With the set-up of Fig. 4a, their value should be increased to about 560 k. Some trial and error may be necessary to find the correct value that gives a satisfactory control range of $P_1$.
The (mono) output amplifier required should, as already stated, be rated at not less than 50 W for satisfactory performance. Together with the filter PCB and mains transformer, it can then be fitted in a suitable case.
Connections between the filter board and output amplifier should be made in screened audio cable. The amplifier and subwoofer drive unit may be interconnected by any twin cable with a cross-sectional core diameter of 2.5 mm² for lengths up to 7 metres.

## Construction (enclosure)

The enclosure is, simply, a rectangular box that must be really solid and have a net volume of about 85 litres. A suitable construction is shown in Fig. 7, but it should be noted that the dimensions stated may be varied by ±30 per cent, as long as the net volume remains about 85

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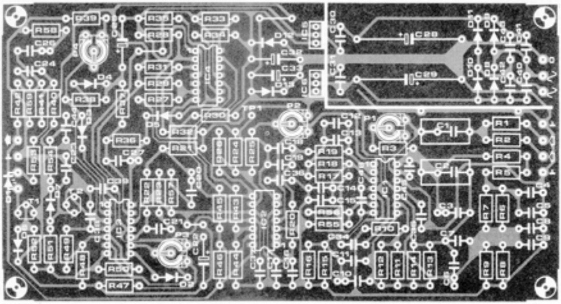

## Parts list

**Resistors:**

$R_1$;$R_2$;$R_{23}$;$R_{59}$ = 27 k
$R_3$;$R_{12}$;$R_{29}$;$R_{31}$ = 4k7
$R_4$;$R_{11}$ = 33 k
$R_5$;$R_{57}$;$R_{58}$ = 3k3
$R_6$;$R_9$;$R_{22}$;$R_{41}$ = 82 k
$R_7$;$R_{40}$ = 680 k
$R_8$;$R_{28}$ = 15 k
$R_{10}$;$R_{17}$ . . . $R_{21}$;$R_{24}$;$R_{26}$;
$R_{27}$;$R_{32}$ . . . $R_{34}$;
$R_{42}$ . . . $R_{46}$ = 10 k
$R_{13}$;$R_{14}$ = 5k6
$R_{15}$ = 8k2
$R_{16}$ = 180 k
$R_{25}$ = 1M5
$R_{30}$;$R_{55}$ = 47 k
$R_{35}$ = 100 Ω
$R_{36}$ . . . $R_{38}$;$R_{51}$ = 1 M
$R_{39}$ = 39 k
$R_{47}$ = 100 k
$R_{48}$ = 470 Ω
$R_{49}$;$R_{52}$ = 22 k
$R_{53}$ = 560 Ω
$R_{54}$ = 270 k
$R_{56}$ = 220 k
$P_1$ = 50 k preset
$P_2$ = 100 k preset
$P_3$ = 1 M preset
$P_4$ = 250 k preset

**Capacitors:**

$C_1$ = 1 μ metal-foil plastic or polystyrene
$C_2$ = 1μ5 metal-foil plastic or polystyrene
$C_3$ = 220 n
$C_4$ = 270 n
$C_5$ = 27 n
$C_6$ = 820 n
$C_7$ = 39 n
$C_8$;$C_9$ = 33 n
$C_{10}$ = 560 n
$C_{11}$;$C_{12}$;$C_{24}$ = 82 n
$C_{12}$;$C_{14}$;$C_{30}$;$C_{31}$;
$C_{34}$ . . . $C_{39}$ = 100 n
$C_{13}$ = 18 n
$C_{15}$ = 6n8
$C_{16}$ = 56 n
$C_{17}$ = 5n6
$C_{18}$ = 150 n
$C_{19}$ = 12 n
$C_{20}$;$C_{26}$ = 680 n
$C_{22}$ = 1 μ;16 V
$C_{23}$ = 47 n
$C_{25}$ = 2μ2;16 V
$C_{27}$ = 330n
$C_{28}$;$C_{29}$ = 470 μ;25 V
$C_{32}$;$C_{33}$ = 10 μ;16 V
$C_{40}$ . . . $C_{43}$ = 22 n
$C_{44}$ = 15 n
$C_{45}$ = 100 p
$C_{46}$ = 68 n

**Semiconductors:**

$D_1$ = LED, red
$D_2$ . . . $D_6$ = 1N4148
$D_7$ = AA119
$D_8$ . . . $D_{13}$ = 1N4001
$T_1$ = BC557B
$T_2$ = BF256C
$IC_1$;$IC_2$ = TL074
$IC_3$ = TL084
$IC_4$ = 1537A (Aphex)
$IC_5$ = 7815
$IC_6$ = 7915

**Miscellaneous:**

$F_1$ = fuse, 100 mA, delayed action
$Tr_1$ = mains transformer; secondary 2 × 15 V at 500 mA
$S_1$ = mains on/off switch
Enclosure as per Fig. 7
Damping material
Drive unit Dynaudio 30W54
2 variovents of 110 mm dia.
Terminals as required
Loudspeaker grille cloth as required
Rubber feet, 4 or 6 as required
Wood glue as required
Wood screws and nails as required

*Fig. 6. The printed circuit board for the filters and output power limiter.*

litres. The holes for the two acoustic resistors (variovents) in the back of the enclosure should, however, always have a diameter of 110 mm. These units attenuate the resonance peak of the drive unit and contribute, therefore, in a real sense to the performance of this relatively small enclosure.

The material should preferably be 22 mm plywood. All edges should be provided with 45 × 45 mm reinforcing battens. Moreover, a 45 × 45 mm cross-piece at the centre of the box will further prevent any panel resonance.

It is best to start with gluing the battens to the panels, followed by the gluing together of the four side panels. Provided the holes for the drive unit and the variovents have been sawn, the front and back panels can then be glued into place. One of these may be screwed, instead of glued, into place, but suitable tape should then be used to seal the gap. This tape should also be used around the frame of the

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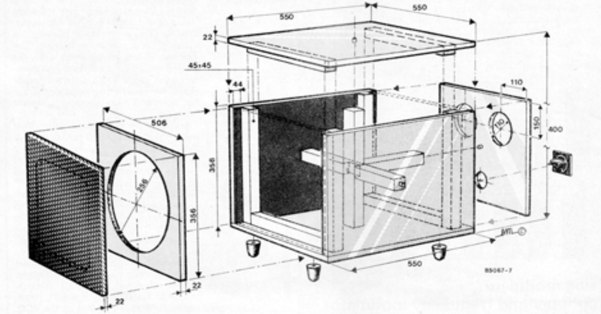


Fig. 7. One possible construction of the enclosure. The dimensions may vary by up to ±30 per cent, but care should be taken that the net volume remains about 85 litres. The diameter of the variovents must be 110 mm.

drive unit to ensure an airtight construction.

Panel resonance can further be prevented by gluing strips of rubber-backed floor covering at the inside of all but the front panels and then covering these panels with 30 mm thick rock-wool.

The photograph on the previous page shows an enclosure of around 85 litres of which the dimensions vary from those shown in Fig. 7.

## Setting the limiter

To set the limiter, a digital multimeter and a 50 Hz test generator are required. Fig. 8 shows how such a simple test generator may be built.

- Set all potentiometers to the centre of their travel.
- Connect inputs L and R to earth.
- Connect the multimeter (set to a DC mV range) to the output and adjust $P_2$ for a reading of exactly 0 V.
- Disconnect the L and R inputs from earth and apply a 50 Hz signal to one of them.
- Connect the output to the (mono) power amplifier but do not yet connect the drive unit.
- Turn $P_3$ fully clockwise (i.e. towards $C_{21}$).
- Set the multimeter to the 20 V or 50 V AC range and connect it to the output of the amplifier.
- Increase the input signal gradually until the meter reads 12 V r.m.s. (i.e. the maximum allowable voltage across the drive unit at 50 Hz). Adjust $P_3$ so that $D_1$ just lights.
- When the input signal is increased, the VCA should limit the output voltage, and this is achieved by adjusting $P_4$ so that the multimeter reading remains 12 V r.m.s. for any further increase of the input level.
- Preset $P_1$ is used to adjust the sound pressure of the subwoofer relative to the satellite loudspeakers.

## Some practical points

It is advisable not to place the enclosure direct onto the floor, but to provide it with four or six rubber feet. This acoustic decoupling prevents any tendency to boom.

As regards the location of the subwoofer, this is best determined by trial and error, because it is impossible to give strict guide lines for every type of living room. It is, of course, wise to place it initially somewhere between the satellite speakers. It is, however, recommended to place it, if at all possible, about 110 cm (4 ft) in front of the satellite speakers. In any case, do not place it direct against a wall or in a corner.

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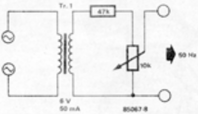


Fig. 8. If an audio tone generator is not available, this simple-to-build 50 Hz generator will do nicely.