Contents

surround-sound subwoofer
Part 2

This active version of the subwoofer described in last month's instalment is a plus for virtually any hi-fi system. Where the low cut-off frequency of the passive version is around 40 Hz, it is down to about 20 Hz in the active subwoofer. With its integral 240 W amplifier, it is the answer for those seeking a realistic bass foundation for their system. The more so, since its building cost is very reasonable.

Design by T. Giesberts

In Part 1 of this article, the benefit was explained that a subwoofer may have for realistic reproduction of hi-fi sound, particularly in audio-visual systems with surround sound. So, what is the value added of this active version, it may be asked. Is a cut-off frequency of around 40 Hz not sufficient for good (bass) sound reproduction?

The answer is yes and no: it depends what you want. For most music reproduction 40 Hz is a good figure: it corresponds roughly with the lowest tone of a double bass. Loudspeakers that can reproduce this frequency with good sound pressure are few and far between. Nevertheless, there are a.f. signals where 40 Hz is not sufficient. This is the case, for instance, when the canon fire in Tchaikovsky's '1812' is to be reproduced faithfully, or when thunder claps are to sound realistic. Also, the sound tracks of films like *Jurassic Park* and *Top Gun* gain in reality if the audio range goes down well below 40 Hz.

Technical data

✔ *Drive unit*	*300 mm (8 in), e.g. Monacor (SPH-300TC), KEF, Radio Shack (40-1024); Parts Express (295-240)*
✔ *Type of enclosure*	*Bass reflex*
✔ *Box dimensions*	*660×406×420mm (incl.legs) 26×16×16⁹⁄16 in*
✔ *Volume of box*	*65 l*
✔ *Frequency range*	*20 Hz to 40 Hz, 50 Hz, 60 Hz or 70 Hz (as selected)*
✔ *Cross-over frequency*	*40 Hz, 50 Hz, 60 Hz or 70 Hz (as selected)*
✔ *Power output*	*245 W into 4 Ω (thd = 0.1%) 130 W into 8 Ω (thd = 0.1%)*
✔ *THD + N at 100 Hz*	*at 1 W into 8 Ω: 0.0046% at 50 W into 8 Ω: 0.001% at 1 W into 4 Ω: 0.007% at 100 W into 4 Ω: 0.0016%*
✔ *Signal to noise ratio*	*90 dB linear (93 dBA) at 1 W into 8 Ω*
✔ *Damping factor*	*>400 (with 4 Ω load)*

Although the question may be asked how far down to go, to which the answer is 'the further the better', a sensible, practical limit appears to be about 20 Hz. This is because the threshold of human hearing is at around that figure. Lower frequencies are 'felt' rather than heard (to hear them would require a battery of loudspeakers that could not be accommodated in the average home. Moreover, even if it could, the possibility of damage to the building at the required volume is not imaginary).

If the cut-off frequency is set at 20 Hz, very good low-frequency reproduction is possible, while the required air displacement can be achieved with normal means. However, with a passive system, this would required an enclosure of a couple of hundred litres, and that again would be unacceptable in the average home. Therefore, what is required is an …

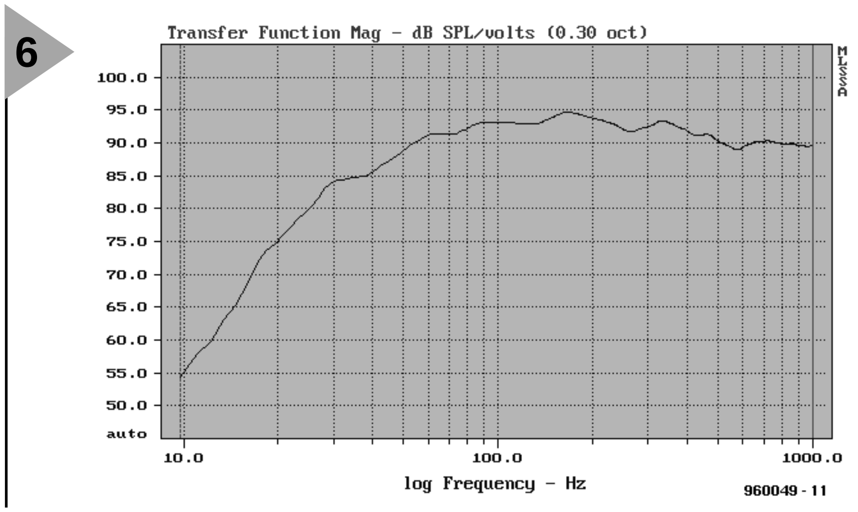


Figure 6. Frequency characteristic of the 300 mm drive unit in its base reflex box, without filter and without correction.

ACTIVE DESIGN

The most notable difference between an active and a passive loudspeaker is the amplifier in the former. In a multiple system, two or more would be needed, but fortunately only one in a subwoofer. The fact that an active design has its own amplifier makes it easily brought into line with the loudspeakers in the system into which it is being introduced.

Another beneficial aspect of an active design is that the necessary filtering can take place before the power amplifier. This filtering is carried out electronically, which has the advantage of offering virtually limitless opportunities for correcting or manipulating the frequency response of the drive unit.

In the present design, these opportunities are taken gratefully, since they allow a relatively small enclosure to reproduce frequencies down to 20 Hz. This is done by measuring the response of the drive unit in its (too small) enclosure and creating a filter with a mirror image of that response. This results in the filter compensating the irregular response of the box until a straight response curve is obtained.

The response of the passive loudspeaker described in Part 1 (using the Monacor drive unit) is shown in **Figure 6**. It will be recalled that the volume of the enclosure is 65 l. The cut-off frequency is about 45 Hz, but a close look at the curve shows that the response begins to roll off at around 85 Hz already. The curve becomes slightly steeper at about 60 Hz and even more so at 30 Hz. The latter is a direct result of the bass reflex vent: above the vent frequency, the roll off occurs at 12 dB/octave (second order) and below it, at 18 dB/octave (third order).

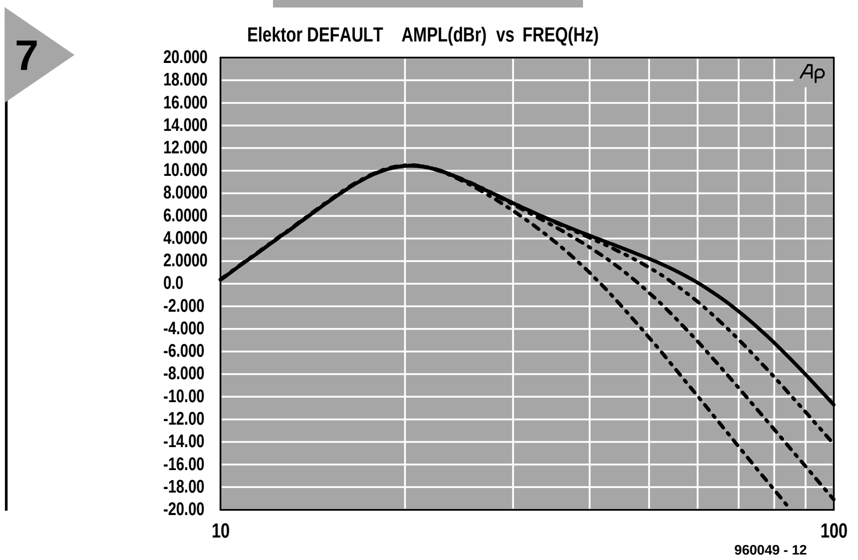
The active design has a basic frequency range of 20–70 Hz. To straighten the response curve, the electronic filter must have a response as shown in **Figure 7**. This curve peaks at 20 Hz (note that it begins to straighten out between 30 Hz and 20 Hz). There are four curves in the figure, because the filter is designed with four switched (upper) cut-off frequencies. This makes it easier for the loudspeaker to be combined with existing systems. Actually, we have jumped ahead slightly, because Figure 7 shows the responses of the active part of the subwoofer.

Figure 7. Response of the combined correction filter and cross-over filter. The four curves refer to (upper) roll-off frequencies of 40 Hz, 50 Hz, 60 Hz and 70 Hz.

The acoustic end result of the design is shown in **Figure 8**, which shows that the response is virtually straight between 20 Hz and 70 Hz. The solid curve is that of the actively corrected subwoofer and is obtained with a standard microphone and spectrum analyser. Comparing this curve with that of Figure 6 shows immediately the enhancement provided by the added electronics. The dotted curve is obtained when the (upper) cut-off frequency is set to its lowest value of 40 Hz.

DESIGN CONSIDERATIONS

The active subwoofer is based on the 30 cm drive unit specified in Part 1, and is housed in the same bass reflex box described in that instalment. The traditional cross-over filter is not used in the active design: it is re-



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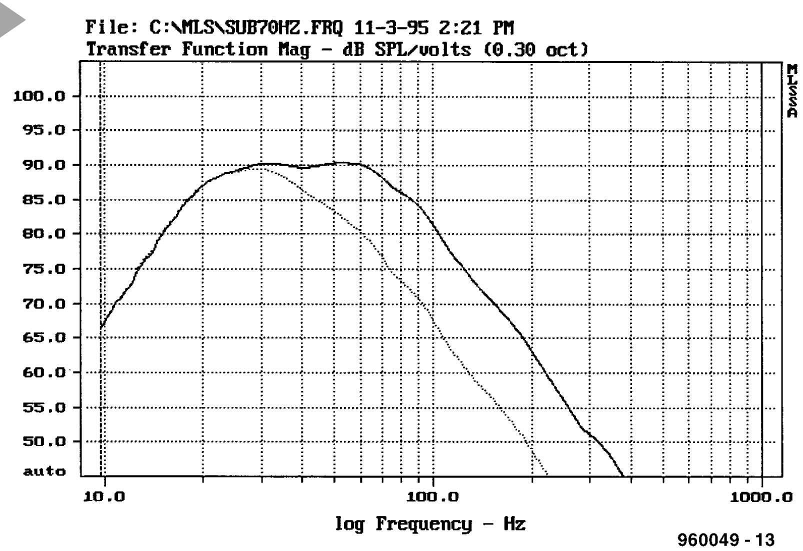

Figure 8. After correction, the frequency response curve of the active subwoofer is straight from 20 Hz to 70 Hz. The dotted curve is measured with a roll-off frequency of 40 Hz.

placed by an electronic filter and a power amplifier.

The electronic filter is a combination of a correction filter and a cross-over filter. It straightens the response curve of the drive unit and can be switched to give one of four different (upper) roll-off frequencies.

Since the filter correction is no less than 10 dB at 20 Hz, the amplifier must provide a reasonable output power: in the present design, 240 W. The amplifier drives both voice coils of the drive unit, which are connected in parallel.

Since the electronic filter has line inputs as well as high-level inputs, the active subwoofer may be driven by a preamplifier (or via the pre-out terminals of an integrated amplifier) or via the loudspeaker terminals—see Figure 9.

The existing a.f. amplifier and the subwoofers must be linked by screened audio cable, not by loudspeaker cable.

The filter, output amplifier and the necessary power supply are housed in a common enclosure that is placed close to the loudspeaker or even fastened on to it.

The filter

The circuit of the filter is shown in the diagram in **Figure 10**. It consists of four distinct parts: correction filter IC_{2d}, IC_{2c}; cross-over filter IC_{2b}, IC_{2a}; drive level indicator IC_3, T_1; and symmetrical power supply IC_4, IC_5.

Operational amplifier IC_{1a} functions as an up-counter for the left-hand and right-hand channels. Its amplification is varied with P_1. High-value resistors R_1 and R_2 ensure that loudspeaker signals can be processed without any difficulty.

The op amp is followed by the correction filter. This is a second-order low-pass type based on IC_{2d}. Its output is added to the unfiltered signal in IC_{2c}. Capacitors C_3 and C_4 limit the bandwidth (as does capacitor C_1 at the input of the amplifier—see **Figure 11**). The correction is enhanced by output buffer R_{28}-R_{29}-C_8, which enables the response of the loudspeaker to change gradually from second order to third order.

The cross-over filter is based on IC_{2b}. It is an active third-order low-pass Butterworth filter that can be set

Figure 9. The active subwoofer is a combination of loudspeaker, amplifier and filter. It can be driven via a line output or via the loudspeaker output.

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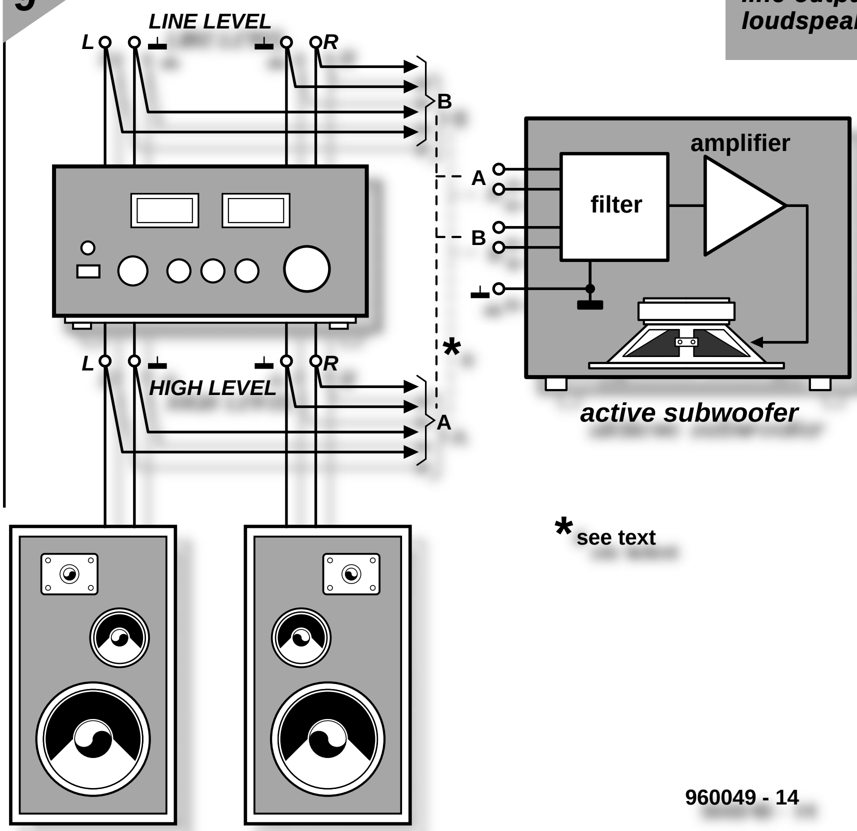

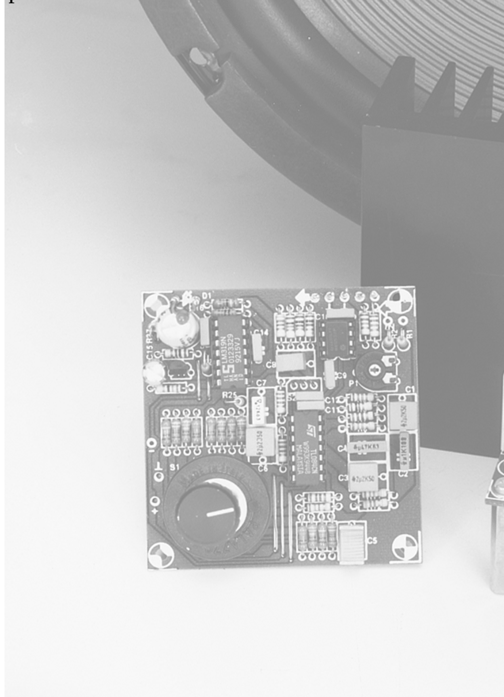

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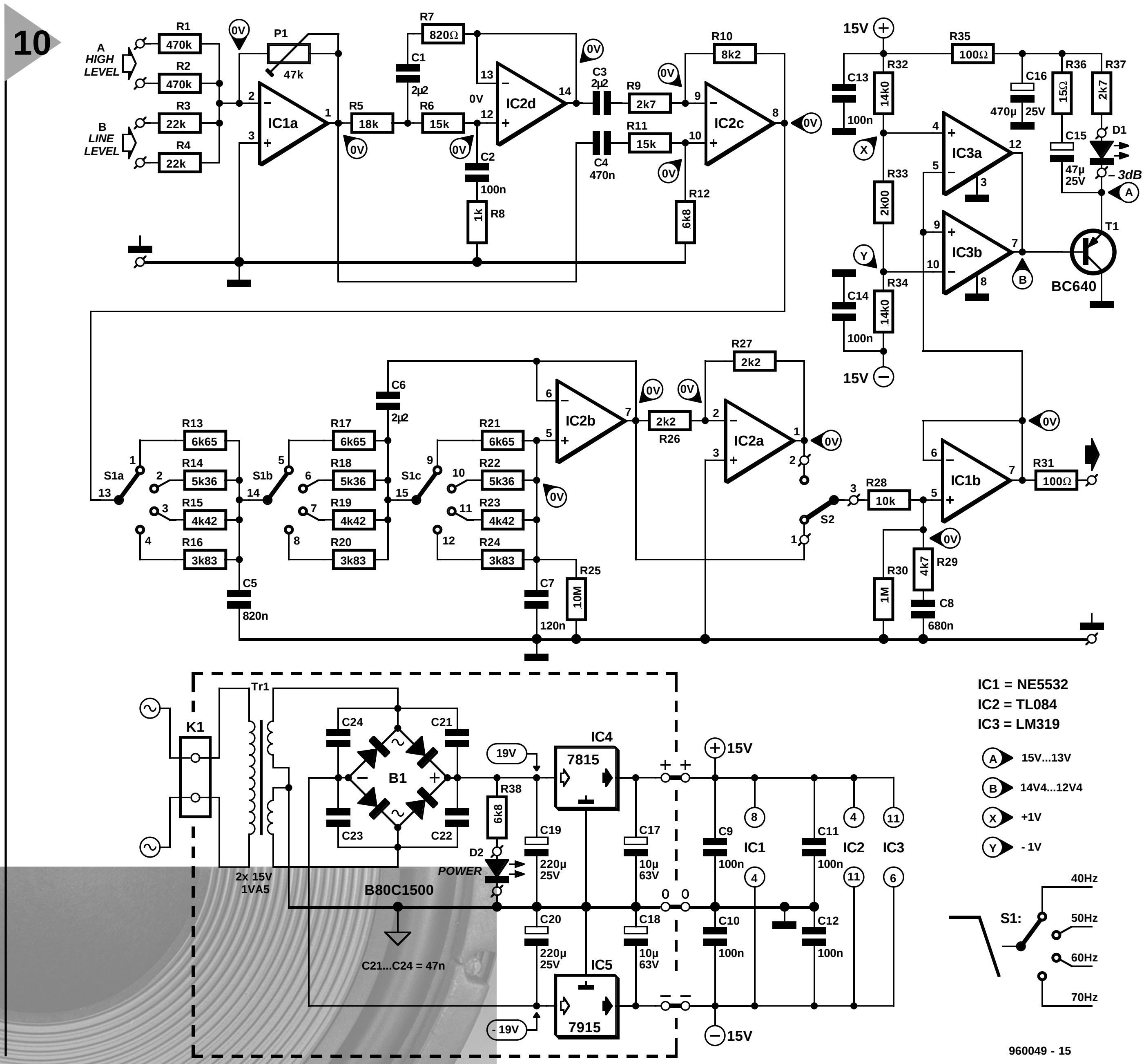

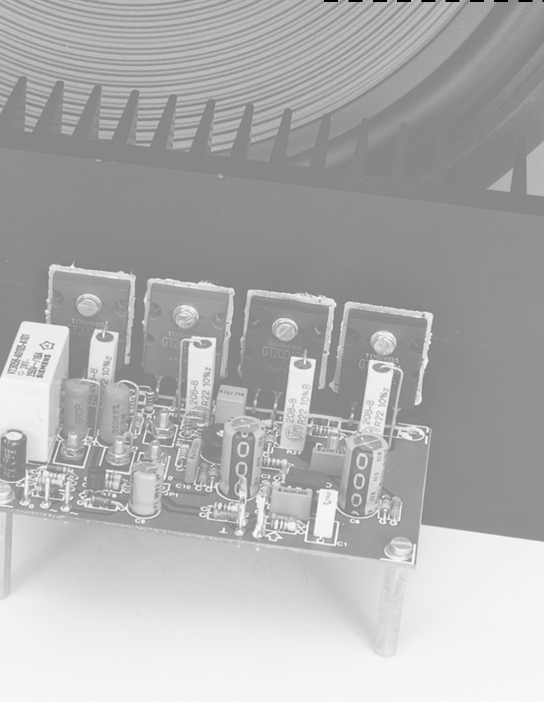

Figure 10. The circuit of the active filter is simplicity itself. The drive level indicator based on IC3 is a boon.

to any one of four different (upper) roll-off frequencies with S_1. With component values as specified on the circuit diagram, these frequencies are: 40 Hz, 50 Hz, 60 Hz, 70 Hz.

The filter is followed by inverter IC_{2a}, so that it is possible to select (with S_2) either the original signal or one that is 180° out of phase with it. This is often an advantage with certain loudspeaker systems.

The filtered signal is applied to the output via buffer IC_{1b}.

The drive level indicator, IC_3 and T_1, is intended as a protection for the loudspeaker: when the amplifier is driven to half its maximum output, diode D_1 lights. This optical signal is a warning to turn down the volume to some extent.

The indicator is based on IC_{3a} and IC_{3b}, which form a window comparator, which is designed such that the led lights when the output voltage of IC_{1b} exceeds a level of 1 Vpeak. Since the output amplifier has an input sensitivity of 1 Vrms, its drive remains about 3 dB below maximum (provided that the warning signal has been responded to).

The brightness of D_1 is enhanced by the high charging current (1 A) through C_{15} delivered by T_1. This also results in a certain amount of afterglow once the peak has passed. Network R_{35}-C_{16} decouples the power line, so that charging pulses do not cause any interference in the filter.

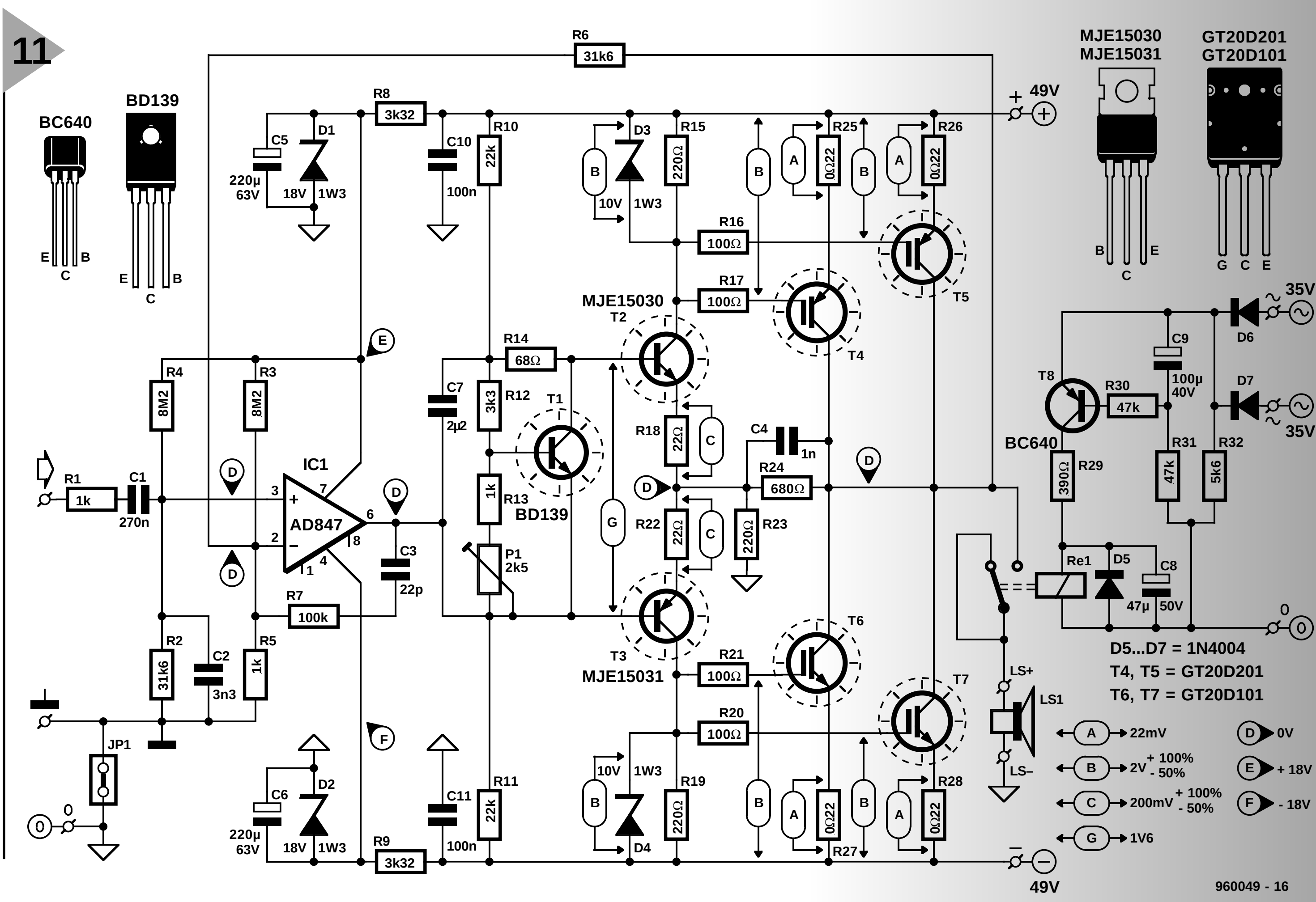

Figure 11. Since the output amplifier does not have to process frequencies above about 100 Hz, its design is spartan. In spit of this, its performance is excellent and its power is sufficient to drive the subwoofer to the very limits of its loadability.

The symmetrical 15 V power supply is a traditional design: mains transformer, bridge rectifier, smoothing capacitors and two voltage regulators, IC_4 and IC_5. Diode D_2 is the on/off indicator.

The power amplifier

The output of the filter is coupled directly to the power amplifier whose circuit is shown in the diagram in **Figure 11**. Considering its output power, the amplifier is fairly compact and straightforward. The compactness is a conscious part of the design, while the simplicity is brought about by the fact that the amplifier needs to perform well only up to about 100 Hz.

The amplifier is a combination of an integrated voltage amplifier and a discrete current amplifier. Since the voltage amplifier needs to meet certain strict requirements, it is based on a very fast op amp (IC_1), the Type AD847 from Analog Devices. Its supply voltage has been made as high as feasible (±18 V) with the aid of zener diodes D_1 and D_2 to minimize the risk of overdriving.

The current amplifier is formed by two 'darlington-like' configurations, each consisting of a medium power driver, T_3/T_4, followed by two parallel-connected Insulated Gate Bipolar Transistors (igbts), T_4-T_5 and T_6-T_7. Network R_{23}-R_{24} ensures that the power stages not only provide current amplification, but also voltage amplification of ×4. This is necessary because IC_1 works from a supply of only ±18 V, whereas the output stages need to be driven to about ±45 V.

'Zener' transistor T_1 enables the correct setting of the quiescent current. For good quiescent-current stability, it is necessary that T_1 is fitted on to the same heat sink as the drivers and power transistors. The stage is designed so that it has a slightly negative temperature coefficient. This means that when the heat sink warms up, the quiescent current, set with P_1, drops a little so that the amplifier cools more quickly

Annoying and possibly damaging switch-on plops are avoided by the traditional relay, controlled by a delay circuit, in series with the loudspeaker. Transistor T_8 conducts only when C_9 has been charged to a certain level via R_{31}: that is, a few seconds after the supply has been switched on.

The delay circuit is powered directly by the secondary winding of the mains transformer. This has the advantage of the relay being deenergized immediately the supply is switched off and not after the reservoir capacitors in the power supply have been discharged.

Next month's instalment will deal with the construction.

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