Acceleration feedback loudspeaker

Feedback from speaker cone reduces distortion and improves frequency response

by D. De Greef and J. Vandewege. Laboratorium voor Elektromagnetisme en Acustica, Gent, Belgium.

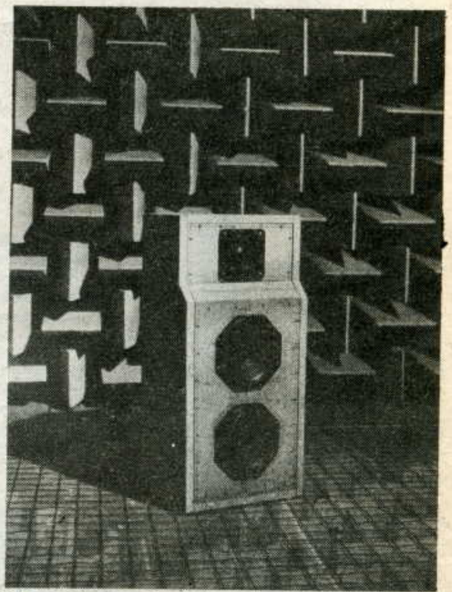
An economical and easily built acceleration-feedback loudspeaker is described. It consists of a two-way, passive-crossover speaker system housed in a compact 44 litre box, and a preamplifier to process the woofer cone-movement feedback signal. Any good power amplifier with a maximum output power lower than 120W r.m.s. can drive this system; no critical adjustments are required. Acceleration feedback is shown to improve considerably the system response below 200Hz. In this region distortion is reduced by a factor 2 to 5, and the power handling capability of the box is increased by 50 percent. In spite of the simplicity of the design, a 20Hz to 20kHz response, flat to within ±3dB, was easily obtained.

A pair of 20cm diameter Philips AD8067/WMFB4 woofers was chosen for our purpose. These speakers have a built-in piezoelectric transducer, and can handle 40W r.m.s. each. Electrically connected in series, and acoustically coupled, they displace the same volume of air as a single 25cm woofer. However, they are mechanically stronger, and cone break-up occurs at much higher frequency (1250Hz for the AD8067/WMFB4 instead of 200 to 400Hz for a 25cm woofer).

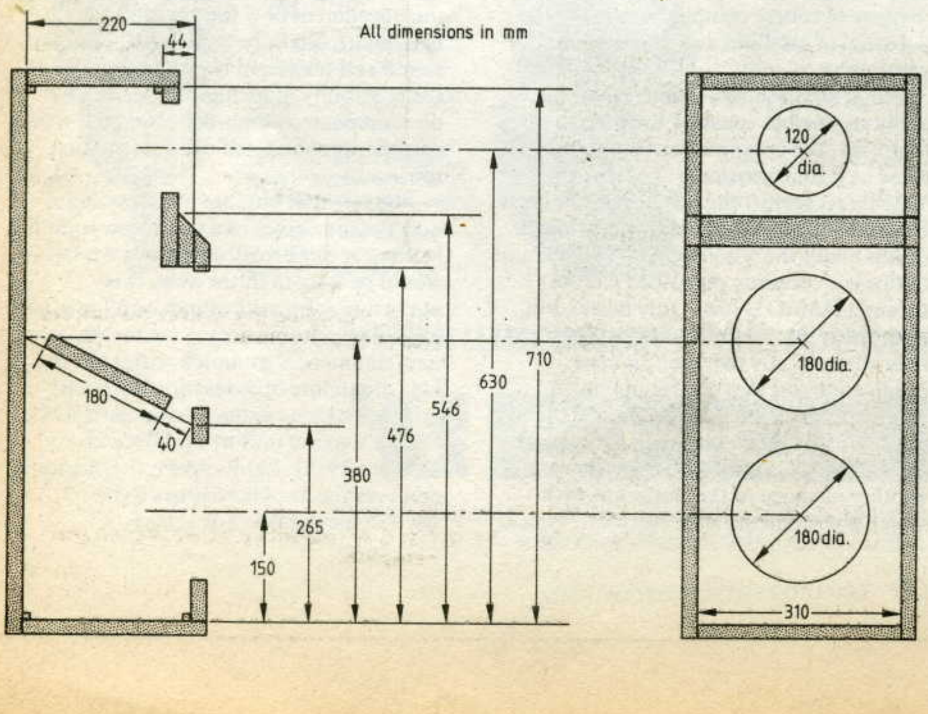
The coupling between the woofers forces them to behave as a system, showing a single fundamental resonance. The 22mm chipboard box shown in Fig. 1 has an effective volume of 44 litres. Its inside dimensions approach the 1.6: 1.25: 1 ratio required for a good distribution of the box resonance frequencies. The oblique partition successfully eliminates the lowest lengthwise resonance of the box at around 260 Hz without deteriorating the acoustical coupling between both woofers. Figure 2 shows the woofer frequency response measured in an anechoic room at 1m on axis, after filling the box competely with polyether foam, which produced a 60Hz woofer resonance with a 0.7 quality factor.

Each woofer cone carries a small printed-circuit board (Fig. 3) on which a piezoelectric acceleration transducer and f.e.t. amplifier are mounted[1,2]. As Reference 3 shows, cone acceleration is proportional to the low-frequency, far-field acoustic pressure generated.

The transducer output was recorded while driving the f.e.t. by a grounded-base n-p-n BC549 to form a cascode stage. Figs 4 and 5 show the results: the 30 to 120Hz speaker response is very well reproduced. Further measurements showed the transducer output below 30Hz to be decreasing, probably because of the finite f.e.t. input impedance. Above 120Hz, the transducer output falls because cone movements are increasingly damped by the surrounding air. Above 1kHz, cone break up and transducer resonances dominate. In the region of interest, the difference between speaker response and transducer signal can easily be modelled as a first-order, 300Hz highpass filter.



The enclosure in an anechoic room: front view showing the soft-dome midrange and both woofers.



ɔortant dimensions of chipboard nclosure.

Feedback system

A source of inspiration was the Philips MFB speaker system 22RH532[1,2]. It has separated power amplifiers for low (40W) and medium to high frequencies (20W), which are incorporated in the box together with a number of filter stages. Woofer feedback is active (loop gain <1) in the 15 to 400 Hz frequency range.

We succeeded in using a single good-quality power amplifier for the entire audio range, by carefully redesigning the feedback system as in Fig. 7. Any good power amplifier can be used, provided its passband reaches as low as 5Hz (for loop stability's sake), and its power output doesn't exceed 120W r.m.s. Loop gain has to be adjusted, once and for all, to 12dB at 100Hz, a 20 per cent fault being hardly noticeable.

A crucial point in our configuration is the 44 Hz low-pass filter in the feedback signal path. It eliminates distortion components of the piezo transducer in the medium range, where transducer distor-

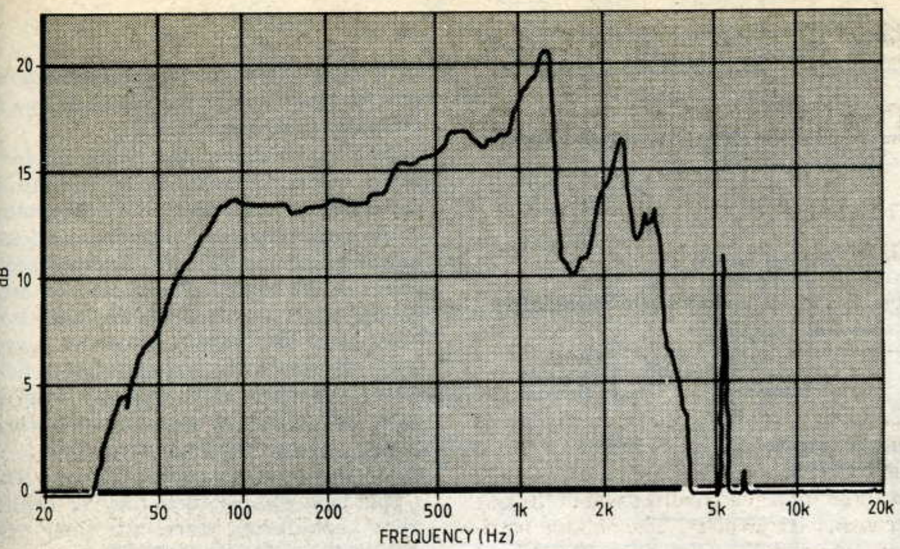
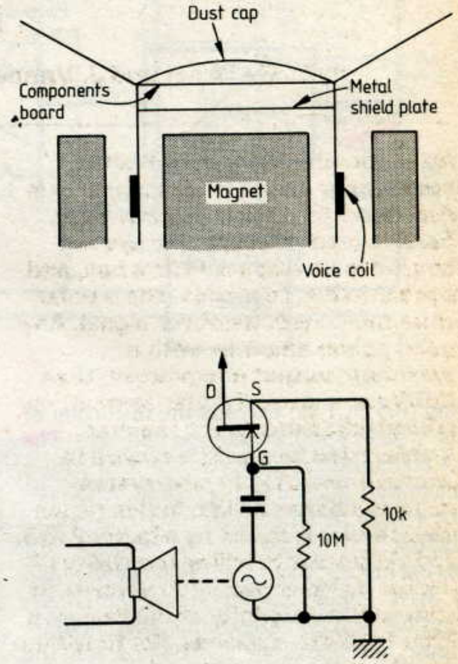


Fig. 2. *Frequency response of the woofers, mounted in the foam-filled enclosure.*

Fig. 3. *Woofer construction with built-in acceleration transducer and f.e.t. stage.*



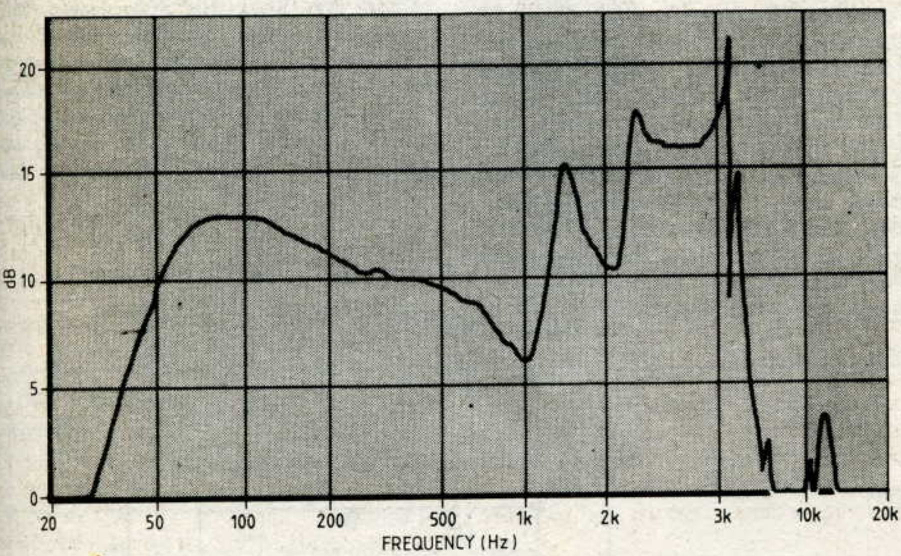


Fig. 4. *Acceleration transducer response with constant speaker voltage applied.*

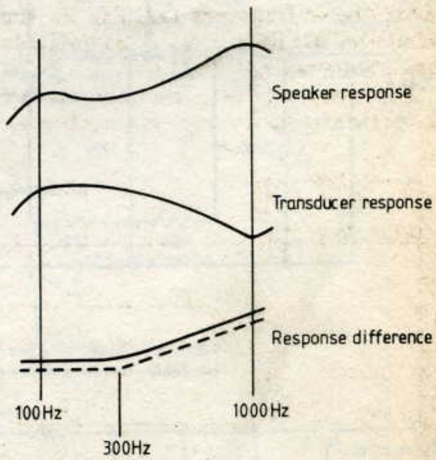


Fig. 6. *Modelling the woofer-transducer response difference.*

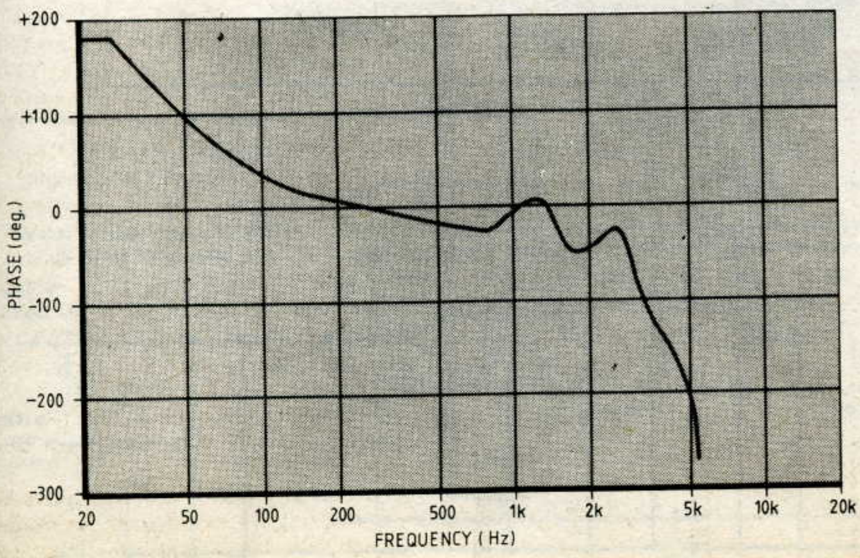


Fig. 5. *Acceleration-transducer phase response.*

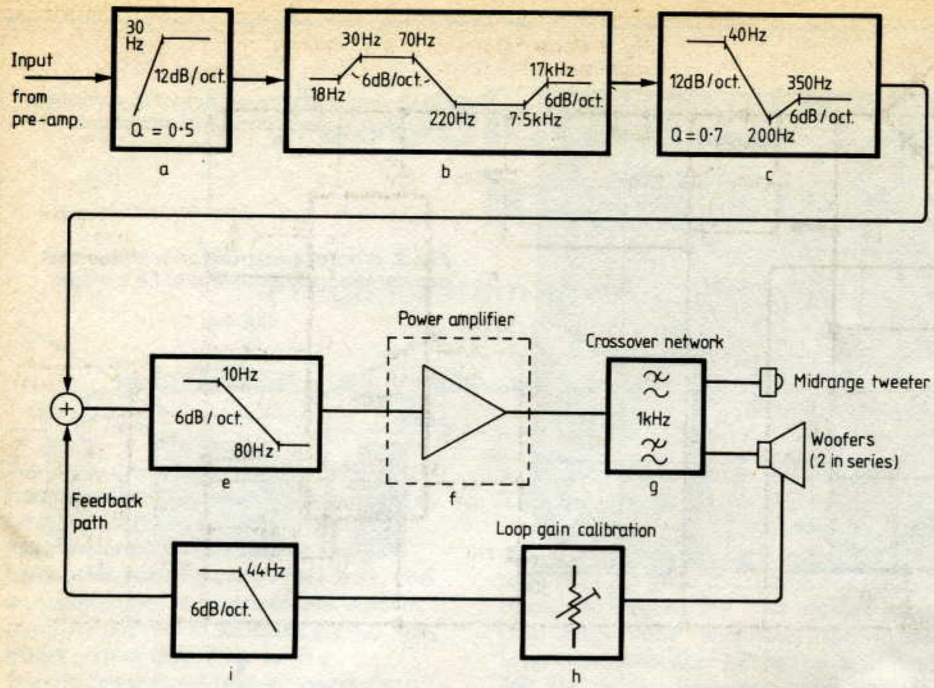


Fig. 7. Block diagram of the acceleration feedback system.

tion (0.5 to 1 %) exceeds the distortion of the woofers (<0.5% around 350 Hz). The 44 Hz cutoff frequency is optimized for a maximum allowable loop gain. Although the system remains stable for a loop gain as high as 22dB, one should not exceed 12dB: excess input signal would provoke too high a drive signal for the power amplifier, causing severe distortion, long settling times and possible destruction of the power stage or the speakers.

The filter stages a, b and c in Fig. 7 form a feedforward compensation of the servo-loop transfer characteristic. Only first-order and low-Q (<0.8) second-order filters were employed to avoid any ringing or overshoot in the system response. The circuitry shown in Fig. 8 is incorporated between the preamplifier and power stage of an existing audio amplifier, and contains all the signal-handling stages required. Except for the connexion of one LM381 input amplifier as part of the transducer f.e.t. cascode stage, its design is very conventional. The 12dB loop gain adjustment R should be set at about 22kΩ for a 34dB power amplifier gain. The whole is fed by a single 24V power supply, shown in Fig.

9. A relay shorts the power amplifier input for ten seconds after switch on, to avoid switching transients.

As Fig. 10 shows, the power-amplifier input signal, generated by a constant servo-system input level, is a complement of the woofer frequency response, as determined by the servo loop. Because audio programme material seldom contains strong very low frequencies, this bass boost does not require excessive power levels. However, the box must be carefully sealed and filled with polyether foam in order not to reduce the woofer's low-frequency power-handling capabilities. As the servo loop is operative as low as 12Hz, a high-pass rumble filter may be needed when reproducing discs: the filter time constants, however, produce an increasing feedback level for those very low frequencies. Subsonic cone movements are strongly damped, obliging the voice coil to stay in the linear region of the magnet system even for higher drive levels. This raises the processable power level, for typical audio programme material, from 80 to about 120W r.m.s. Figure 11 shows woofer distortion when a 25W sinusoidal signal is applied to the box: closing the feedback loop dramatically decreases low frequency distortion.

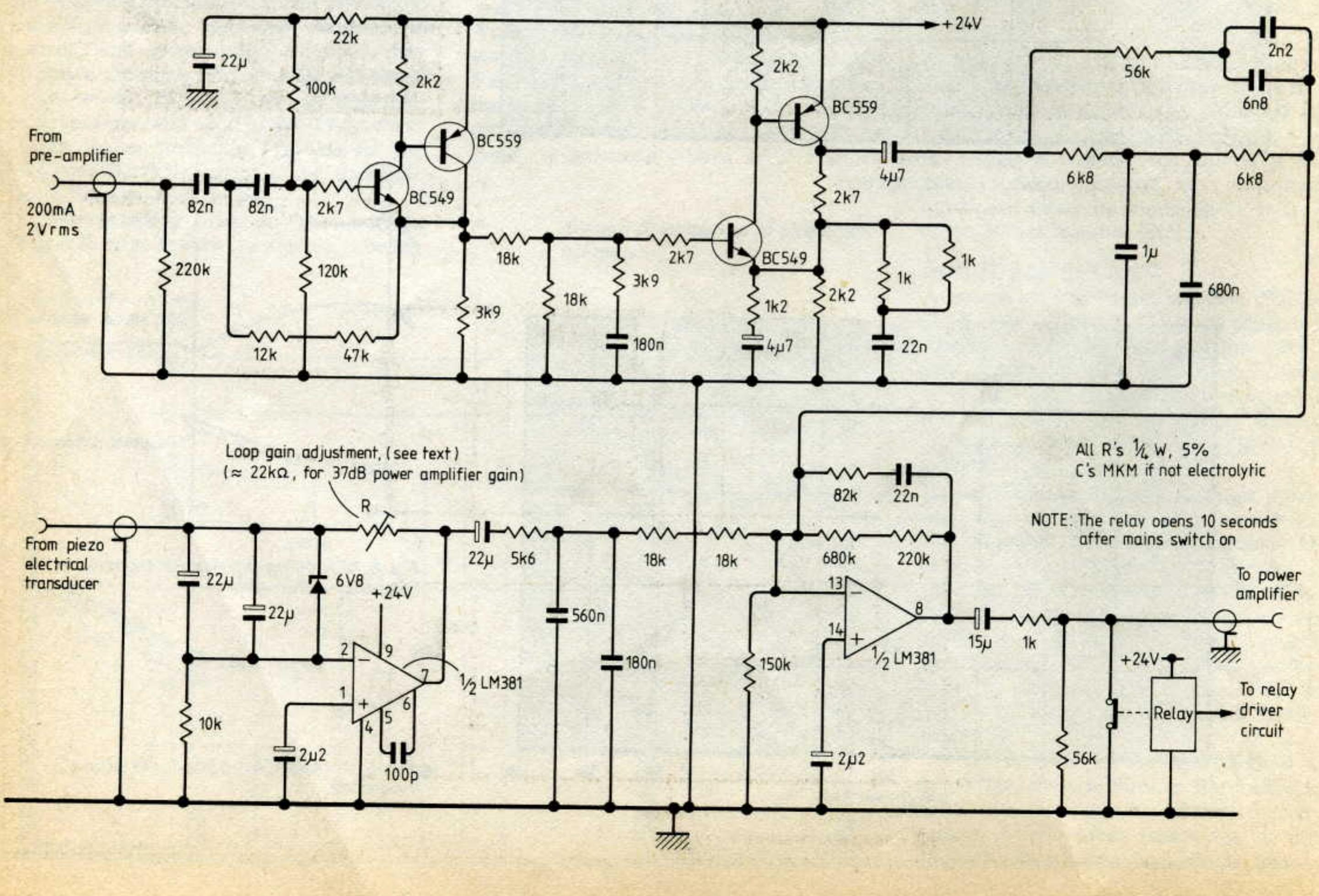


Fig. 8. Filter and feedback stages.