

tance. It also indicates the way to compensate it, namely by the series connection of a positive capacitive reactance of the same magnitude. In acoustics terms, this amounts to placing a compliant volume of air behind the diaphragm, enclosed in an airtight chamber—see Fig. 4. Note that this action is not in any way a frequency-selective tuning operation: in principle, it is rather a broad-band reactance annulling process.

The volume of the air chamber is calculated by multiplying the throat area, S_t , by the length in which the horn doubles its cross-sectional area, and then by 2.9. Typically, this volume is small compared with the enclosed volumes required for infinite baffle designs.

For finite horns, the throat-impedance curves exhibit a degree of periodicity, with the depth of the oscillations increasing as the horn is made shorter and thinner. Fig. 5 shows the behaviour of the real and imaginary parts of the throat impedance, computed by Olson, for a horn with a mouth circumference of $0.71\lambda_c$, where λ_c is the wavelength at the cut-off frequency. Once the flare constant and the size of the mouth have been decided, the length of the horn depends only on the size of the throat. Often, the desirable length is quite impractical at low frequencies.

Practical constraints

Ideally, the horn would possess a wide mouth, say, 8.3 m circumference for good matching to the room at 40 Hz: this would entail a length of around 5 m. Some design compromise is clearly indicated if horn-loaded enclosures are to be adopted for semi-fixed or even portable applications. A number of actions can be taken to ease the dimensional limitations. The best-known of these is to fold the horn back onto itself once or twice to make a more compact, box-shaped structure. Less well-known, perhaps, is the method used by Lee in his catenoid design (Ref. 3), or that of P.W. Klipsch, in which the mouth of the horn is made to illuminate the room from one of its corners.

The effectiveness of the Klipsch method can be understood by considering the fact that plac-

ing a sound source close to a solid plane produces an in-phase image behind the plane. Similarly, a source located near the intersection of two planes gives rise to two images, and near a corner of a rectangular box three in-phase images accompany the source. The effect of placing the mouth of a horn near a corner is to quadruple the effective mouth area, which very usefully relaxes the earlier stated conditions on mouth circumference: it halves the circumference.

The klipschorn

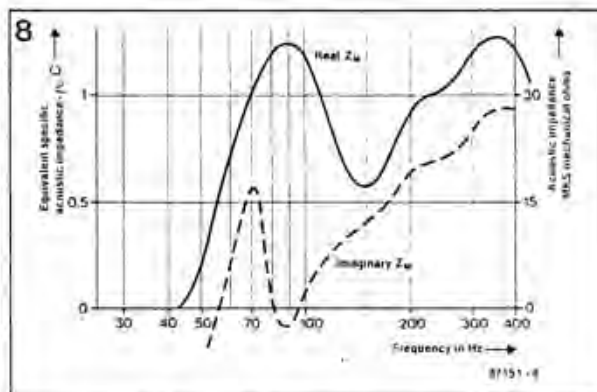
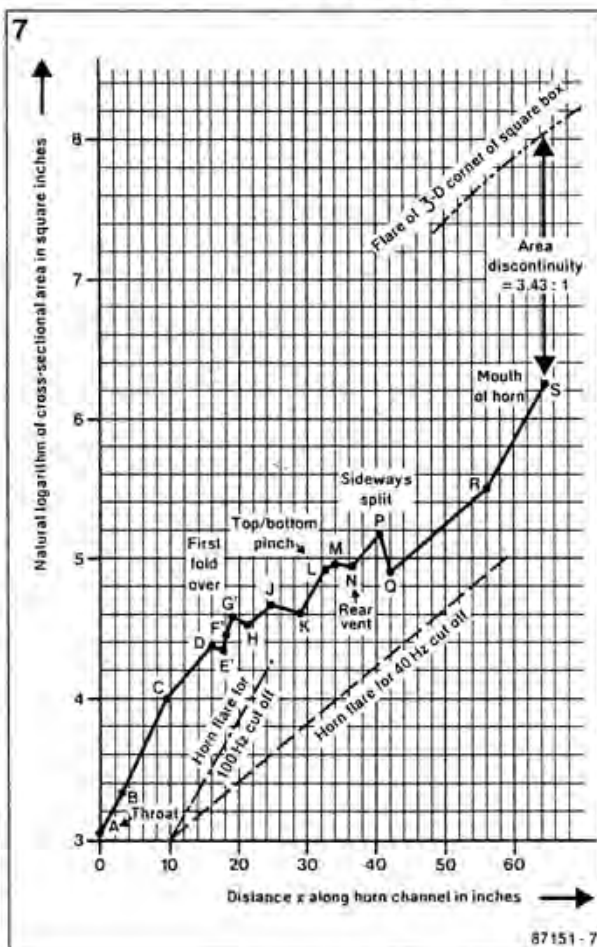
P.W. Klipsch described a *Low Frequency Horn of Small Dimensions* (Ref. 4) in 1941. His experimental work was cut short by the Second World War, but provided enough data to establish the final design with confidence. It included all the design improvements described in the foregoing section in an ingeniously designed cabinet pictured in Fig. 6.

The design cleverly conceals a doubly split reflex horn of over 1.5 m in length, and makes use of the room walls for two sides of the horn. The mouth of the horn is formed by two rectangular, vertical slots (including the contiguous images in the walls and floor) which make a phased array that helps to beam sound in the horizontal plane, and at the same time increases the specific acoustic impedance.

I shall not repeat or even summarize Klipsch's detailed analysis, but rather assume his measured results and apply them to the present project, which consists of a klipschorn enclosure and a Richard Allen CG12 driver unit. Klipsch used a mains energized Jensen 12, 12-inch driver, which enabled some acoustical measurements to be made via the voice coil terminals simply by switching on or off the magnetic field. The wedge-shaped air chamber has a volume of 64 l of which 9.8 l were taken up by the driver unit.

The chamber, by virtue of its pyramidal shape, was free of mid-range resonances and required no damping (which would reduce efficiency in any case).

The piston diameter of the cone (10.5 in) gave an area $S_0 = 0.0558 \text{ m}^2$, which was re-



duced to 0.0322 m^2 at the entrance to the throat to give a ratio $S_0/S_T = 1.73$ in Eq. (11). This was found to be too large at the lowest frequencies, and so a "rubber throat" was devised to give an effective throat area of 0.0644 m^2 at 40 Hz, reducing to 0.0322 m^2 at 100 Hz. The "rubber throat" was brought about by making the first section of the multi-flared horn cut off at 100 Hz, and the rest of the horn at 40 Hz.

The throat opened into a split horn with symmetrical channels pointing up and down for the

100 Hz cut-off section. The two channels folded around the top and bottom of the air chamber, constricting in the lateral dimension, but flaring in the vertical.

The 40 Hz cut-off flare constant was approximately maintained with the aid of a succession of short linear flares for ease of construction.

The sharp corner of the room was hidden by a fillet plate which deflected the now merged sound from upper and lower channels sideways between cabinet sides and walls,