The Daline

A decoupled anti-resonant line loudspeaker
by Robert Fris

THE basic parameters affecting loudspeakers intended for a domestic environment may be considered under three headings: (1) *cabinet*, its mounting position, size, and the resulting height of sound image; (2) *performance*, in terms of maximum acoustic output, power handling capacity, efficiency, frequency range, deviations in amplitude response, distortion, and transient response; and (3) *cost*.

The size of the cabinet determines the low frequency performance almost directly, the upper frequency range being unaffected. The first consideration, then, is to optimise the low frequency performance, and the performance over the rest of the audio range can be determined at a later stage depending on the initial results.

An analysis of the bass loading principles revealed that the tuned pipe appeared to offer the best low frequency performance potential. The manner in which it is utilised is by exploiting the fundamental 'anti-resonance'.

This occurs in an open pipe at the frequency whose acoustic wavelength is four times the length of the pipe, ie.. $l=\lambda/4$. The drive-unit is coupled directly to one end of the pipe, as shown in fig. 1. Taking the instant when the cone is at its peak negative displacement, a compression will be expelled into the pipe and transmitted along it to reach the open end one quarter of a cycle later. Meanwhile, the cone has continued to its position of zero displacement. The compression is expelled into free air, sending a rarefaction back along the pipe to the cone. On reaching the cone, another quarter of a cycle later, it finds the cone at its peak positive displacement and applies a sucking force to it, tending to reduce its amplitude.

This action, which is of course continuous, results in a lower cone amplitude for a given input power and frequency, and augmented radiation from the open pipe.

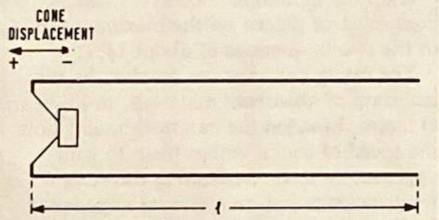
An analogy is that of the quarter-wave stub, which, when short-circuited, presents a theoretical open circuit to the generator. In practice, the air is not a short-circuit and neither is the pipe lossless. The air presents a low impedance consisting of radiation resistance and air mass close to the radiator.

The expelled pressure wave from the pipe proceeds into this terminating impedance in much the same way as current does from a transmission line, producing power dissipation, and hence radiation, in the resistive element.

The control over the cone amplitude is an important factor, as a significant improvement in low frequency power handling capacity and/or distortion can be obtained.

A drive-unit mounted on a true infinite

FIG.1 ¼ WAVE PIPE ($l = \lambda/4$)



baffle or in a sealed enclosure, so that radiation from the cone is not augmented acoustically, will exhibit, for a fixed power input, a varying amplitude with frequency. At frequencies above that whose wavelength is equal to the cone circumference, the cone is loaded by the radiation resistance which is constant. Below that frequency, the cone is loaded by the mass of air immediately in front of and behind it, the reactance of which varies with frequency. It is over this range that the cone radiates as a point source with a theoretically hemi-spherical radiation pattern, and cone velocity inversely proportional to the frequency.

As the frequency at which the turnover between mass and resistive loading is dependent on the size (and shape) of the cone—the optimum shape being circular—a different amplitude will occur at a given frequency for differing cone sizes. In addition, the radiation resistance is proportional to the square of the cone area, so that if two different size drive units are compared, the cone amplitude curves will appear as shown in fig. 2. Strictly, these curves and those in fig. 3 show cone *velocity*, not amplitude; but they have been rationalised to give an apparently constant amplitude over the resistively loaded HF range (whose amplitude is really already inversely proportional to frequency), so that the effect of mass loading (giving an inverse square-law to amplitude) is more evident.

It can be seen that the smaller cone always has a higher amplitude for a given frequency and input power, putting heavier limitations on power handling capacity.

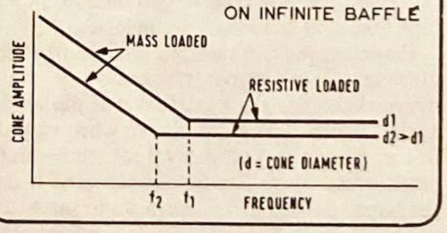
The second factor relating to cone size is the efficiency, which is proportional to the square of the cone area but also inversely proportional to the cone mass. However, the mass is, in practice, more or less proportional to the area, with the result that the efficiency becomes approximately proportional to the area.

For the sake of maximum radiated output, the cone should be as large as possible; but, neglecting the problems due to cone support, break-up modes, etc, the mass would be so high as to seriously disable high frequency output and, more important, transient response. In contradiction, to maintain the transient response at an acceptable value, the cone should be as light and, therefore, as small as possible.

In some loudspeakers, incidentally, to obtain a reasonably efficient low frequency performance, a very large cone 'super' bass-unit is employed, the use of which is supported by the argument that a good transient performance at low frequencies is not necessary, the harmonics of the transient being reproduced by the higher frequency drive units. Two arguments that arise from this are that the bulk of the energy contained in a transient is at the fundamental (try standing in front of a pedal drum), and that the amplifier is not fully able to stop the ensuing resonance. Such an acoustic hammer is maybe ideal for juke boxes (listen to the bass!) but is a poor attempt at true reproduction.

The first compromise, then, is with cone size, one approach to its resolution being to employ as small a bass cone as possible

FIG. 2 SIMPLIFIED CONE AMPLITUDE/FREQUENCY CURVES AT CONSTANT POWER ON INFINITE BAFFLE



commensurate with sufficiently high available output power at low distortion. For high power systems it is preferable to use several small bass units rather than one large unit, so that the mass per motor is minimised even though the total moving mass is as high. However, as will be seen later, one surprisingly small bass unit, when acoustically loaded to best advantage, can perform better

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at low frequencies than a large one not so loaded.

Referring to fig. 2, it can be seen that, in the mass-loaded region maximum input power before overload is dependent upon the frequency, such that a compromise exists between input power and low frequency extension, the condition being progressively worse for smaller bass units.

If a small bass unit is loaded by a tuned pipe, a considerable improvement can be effected by impeding the cone amplitude over the range at which it would be mechanically overloaded at high signal levels. By applying a suitable choice and quantity of damping materials, the cone 'amplitude' curve can be doctored to appear as shown in fig. 3.

As the 'amplitude' is constant over the range f_1 to f_2, the frequency at which mechanical limiting first occurs is shifted downward by the same amount. The level portion intersects the unmodified curve of the larger unit, so, at and below the intersection frequency, the effective radiating area equals and then exceeds the area of the larger cone.

This is achieved neither at the expense of transient response, as no mass is added to the cone, nor low frequency output, as this is radiated from the pipe. As the impedance presented to the cone is constant over this range, it must follow that the pipe radiates with an increasing amplitude to compensate for the changing air impedance. This can be observed when holding a piece of light-weight paper in front of the pipe's open end.

Ringing in the pipe does not occur at these frequencies because the anti-resonance is by nature restrictive of cone motion and therefore limits its own source of energy, but above this range the pipe enters into a series of harmonic resonances, all of which should be suppressed.

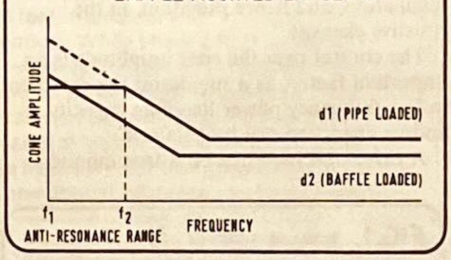
The transmission line loudspeaker achieves this with a taper of the pipe and very careful dense packing of absorbent materials. The loading on the cone above the anti-resonance is nearly constant and resistive, the value of which is high. The efficiency is low, requiring a large bass unit to gain what is lost. Unfortunately, problems associated with cone mass, cone break-up, overall size and cost arise; on the other hand, coloration due to internal reflections is negligible, as rear radiation from the cone is absorbed in the pipe except at the lowest frequencies.

However, the extra output emitted from the pipe can create a rather bass-heavy impression when the loudspeaker is placed against a wall, and extremely so when placed in a corner. The TLS is ideal for studio and exterior use where free-field positioning makes the large size and low frequency output unobtrusive. A few compact TLS models are available but these have rather high cut-off frequencies giving little improvement over sealed enclosures of the same size.

Alternative to absorbing the mid-range radiation in a heavily damped pipe, the pipe may be decoupled from the drive-unit above the anti-resonance range. A low-pass filter inserted between the bass unit and the pipe would take the form of a cavity as shown in fig. 4. (Such an enclosure would behave like a Helmholtz resonator or reflex system if the pipe were short compared with the wavelength.) The frequency of turnover, at which the acoustic capacitance of the cavity begins to shunt the acoustic resistance of the pipe, will be dependent upon the size of the cavity and of the orifice. At frequencies above the anti-resonance the pipe offers a high impedance to the cavity, the cavity presenting a lower impedance to the cone, so the rear radiation may be contained in and absorbed by the cavity. As the frequency is lowered, the cone is progressively coupled to the pipe. If the cavity's Helmoltz type resonance and pipe's anti-resonance are coincident the drive-unit will be mass loaded (but stiffness constrained) by the cavity on the upper side of its resonance and mass loaded by the pipe on the lower side of its anti-resonance.

Extra bass extension may be obtained by tuning the pipe a little below the cavity, in which case, between the two centre frequencies the mass elements add and the stiffness components cancel, maintaining consistent mass loading. Care must be exercised not to allow the cavity resonance to coincide or

FIG.3 BASIC CURVES COMPARING SMALL PIPE-LOADED BASS UNIT WITH BAFFLE MOUNTED LARGER UNIT



overlap the pipe fundamental resonance, so a limit must be placed on the maximum ratio of the two frequencies of about 1½:1.

The cavity and pipe are damped by the inclusion of absorbent materials, to lower the Q factor, broaden the bandwidth, and slow the speed of sound within them to gain apparent volume. Separating the centre frequencies causes an electrical impedance rise in the bass unit as the resistive loading on the cone is reduced at the cavity resonance, but so long as this is not excessive, as would be caused by insufficient cavity damping, no disturbing effects should occur.

The main advantage with this, the Daline system (Decoupled Anti-resonant Line) is that the midrange efficiency can be better matched to the low frequency efficiency when concentrated in ¼-sphere of space. The midrange efficiency is higher than an absorbent line would provide, and because of the ability to vary the parameters of the pipe without upsetting midrange performance, a good degree of control is possible.

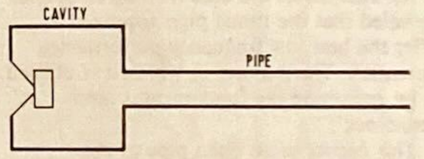
A mild negative taper has been introduced to the pipe to aid the elimination of harmonic resonances and broaden the response of the anti-resonance. In such a lightly damped pipe the depth of taper must be limited to prevent reflections from the pipe walls. A negative taper with a 1½ : 1 reduction ratio in area has been found satisfactory, but it is yet to be established what is the optimum. The minimum area of pipe is equal to the cone area, but it could probably be reduced to about half the value without introducing any noticeably detrimental effects.

The Daline system can be applied to any size bass unit, but offers the best results from units of about 3½ to 5 ins. cone diameter, because of the low mass of such cones. Over the anti-resonance range the effective radiating area increases by up to a factor of five or so. This means that a 4 in. cone will have a low frequency amplitude similar to that of a baffle loaded 10in. cone for the same input power. Doppler distortion problems at this frequency are then no worse than for the larger unit. The size of a sealed enclosure for the larger unit to radiate such low frequencies would be enormous, whereas the Daline model is quite small, occupying no more than 1·1cu. ft. (internal).

The cut-off frequency is determined by the combination of drive-unit parameters and cabinet dimensions, so the designer is not limited to one cut-off frequency for a particular drive-unit, but is free to establish whatever size cut-off compromise he wishes. The best compromise appears to place the cut-off frequency around 0·7 of the frequency of the drive unit's free-air resonance. For a full-range system this means that a drive unit with a free-air resonance of 30 Hz is required to obtain an output down to 20 Hz. The majority of large loudspeakers have a cut-off at about 40 or 50 Hz, and this is plainly evident when listening to a pipe organ or bass drum; but some compromise must be accepted with any speaker of practical dimensions.

Several loudspeaker systems have been constructed on the Daline principle and the one that best exemplifies the advantages of the system is described below. It employs

FIG.4 ADDING A LOW-PASS FILTER



one twin-cone drive-unit of 6½in. diameter and 55 Hz free air resonance, and covers the range from 35 Hz upwards. The quality is certainly not high in the treble region, but is perfectly adequate when one considers that a pair of these costs under £20 to build (at the time of writing).

The treble range is reproduced rather enthusiastically by the centre cone, and it has been found that a worthwhile improvement can be effected by inserting a piece of ¾in. thick sponge rubber in the centre of it. The sponge should be cut into a disc to fit easily inside the cone, leaving a ¼in. lip of cone protruding, and fixed in with a little light glue. Although this appears to be a somewhat hit-and-miss approach, a substantial improvement can be made and further experimenting can be undertaken by the constructor if desired. The overall efficiency when modified is about 1%, so with a power handling capacity suitable for a 15 watt-per-channel amplifier, reasonable sound levels are

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obtainable in a moderate size room.

Figs. 5, 6 and 7 show constructional details. Complete air-tightness is imperative; if doubts arise over the condition of any joint in this respect, it must be sealed with extra glue or sealing material. Panels should be cut to the sizes indicated in the Materials List; it is preferable to have the timber machine-sawn to ensure accuracy and hence trouble-free assembly. Plywood is preferred to chipboard for cleanliness of sawn edges, strength and long-term stability. It is also more expensive. The following is a recommended building sequence.

(1) Cut out and drill holes in FRONT. The drive unit hole is arranged to taper out from 5½in. on the inside to 6½in. on the outside of the panel to prevent a column of air being formed in front of the cone. Care must be taken, however, not to interfere with the mounting bolt holes. The best order of approach is to cut out the main hole with parallel edges, then drill the mounting bolt holes, followed by chamfering of the sections of the main hole between the mounting bolt holes, avoiding the parts of the edge immediately adjacent to them.

(2) Glue and pin TOP, BOTTOM and SIDES, in that order, to the FRONT. Ensure that all panels are square to each other when pinning.

(3) Leave while glue dries.

(4) Glue in PARTITION ensuring that it is square with FRONT and SIDES.

(5) Glue in SUPPORTS and apply dabs of glue to the surfaces of the front section of the pipe.

(6) Insert ½oz. of TERYLENE WOOL, well teased out, in the front section of the pipe and ensure that it is in contact with the glue spots.

(7) Glue in SECTION, ensuring that it is glued all along the edges in contact with the SIDES and PARTITION.

(8) Leave to set.

(9) Glue the BATTENS in position around the TOP, BOTTOM and SIDES.

(10) Glue BRACING onto BACK.

(11) Leave to set.

(12) Insert ½oz. of TERYLENE WOOL, well teased out, as before, in the rear section of the pipe, held in by dabs of glue.

(13) Mount the drive unit onto the FRONT and wire up to the connector on the BACK, taking care to connect the positive tag of the drive-unit to the positive terminal of the connector.

(14) Tease out and insert 1oz of TERYLENE WOOL in the cavity and glue the SPONGE SHEET onto the inside of the BACK so that it covers the BRACING but leaves a 1in. gap all round the edge of the panel in order for it not to interfere with the BATTENS.

(15) Screw BACK onto BATTENS with a strip of Bostik SEALING STRIP in between.

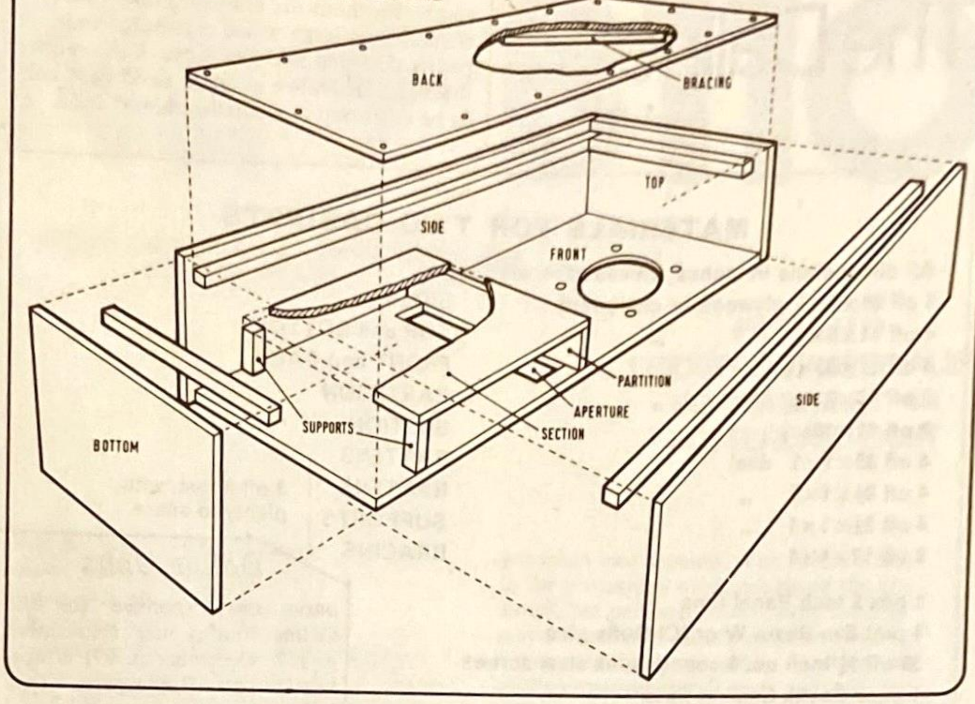
(16) Connect the loudspeaker to an amplifier fed by an oscillator set at 40Hz, or by hum induced by a finger applied to a sensitive input. Listen around the joints of the loudspeaker (still with the finger on the amplifier!) to check that no whistling or chuffing noises are present. The volume should be as high as possible without overloading the amplifier or loudspeaker. If extraneous noises are heard, a leak must exist and should be rectified by applying more glue or sealing material.

Finally, hold a piece of light-weight paper over the aperture and firmly against the top edge of it. Check that the paper flaps vigorously at high volume of the test tone. If it doesn't, an internal leak must exist (i.e. between PARTITION and SIDES) or a gross over-estimation of damping material quantity has been made.

The speaker is now ready for final embellishments and operation.

Like the TLS, the Daline system exploits the anti-resonance of the tuned pipe to the same advantage, permitting truer reproduction

FIG. 5 EXPLODED VIEW OF THE DALINE



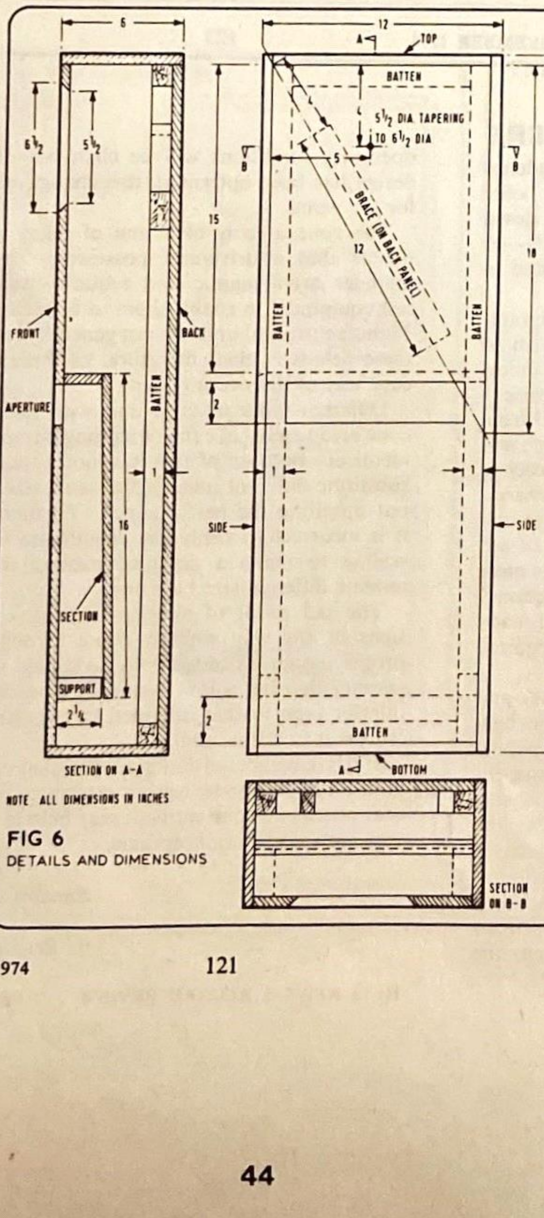


FIG 6
DETAILS AND DIMENSIONS

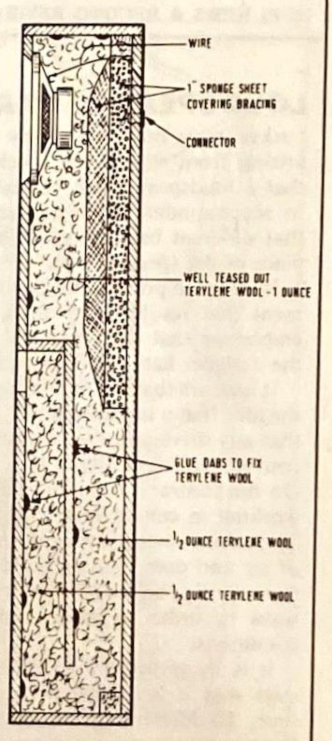


FIG. 7
DAMPING MATERIALS

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of any low frequency signal (including rumble) without the notorious boom that characterises large sealed enclosures and poorly designed reflex systems. But, unlike the TLS, the Daline allows a small bass unit to be employed in a smaller cabinet for a similar efficiency and low frequency cut-off, concurrent with a significant improvement in transient response resulting from the lower cone mass, and considerable reduction in complexity and cost. Two useful products of this are that the smaller bass unit may be operated to a higher frequency, reducing the number of drive units required for a high quality system, and the subsequent cost saving, not only from the smaller bass unit and cabinet, but from the lower number of drive units and crossover components.

Although the system design parameters are not critical, it is not necessarily possible to substitute the bass unit for another type in a particular cabinet, so it is important to use the specified drive unit in the model described. Two units may have the same physical dimensions and even chassis construction, but unless they have the same model number they can possess quite different dynamic parameters, so it is not a safe bet to fit *any* drive unit of 6½in. diameter.

The Daline system is not limited to use with any particular size of drive unit, but offers best results, for the reasons given earlier, with as small a bass unit as possible, the optimum so far established being 5in., giving reproduction down to below 30Hz from a cabinet the same size as the one described (but with a completely different internal construction).

The whole aim of loudspeaker design is to produce a system that renders reproduction as close to perfection as possible, and as development continues this aim is being gradually approached. With the Daline system the imperfections are at least contained in a smaller box.

MATERIALS FOR TWO CABINETS

All dimensions in inches, unless otherwise stated.

4 off 34×6×½	plywood or chipboard	SIDES
4 off 11×6×½	"	TOP and BOTTOM
4 off 11×33×½	"	FRONT and BACK
2 off 11×2×½	"	PARTITION
2 off 11×16×½	"	SECTION
4 off 33×1×1	deal	BATTENS
4 off 9¼×1×1	"	BATTENS
4 off 2¼×1×1	"	SUPPORTS
2 off 12×1×1	"	BRACING

(Battens, battens, supports, bracing: 3 off 8 feet, with plenty to spare.)

1 box 1 inch Panel Pins
1 pint Evo Resin W or ICI Dufix glue
30 off 1¼ inch no. 6 countersunk steel screws
1 pack Bostik Sealing Strip
8 off 1¼ inch 2BA Bolts, Nuts and Washers
4 ounces Terylene Wool (available from Pet shops for fish tank water filters)
2 off 18"×9"×1" Closed Cell Sponge Sheet
2 off RS Components 6½" Longthrow loudspeakers
Offcut of ¾" Closed Cell Sponge Sheet, for h.f. cone modification, if desired

Note: RS Components do not supply direct to the public, but the drive units can be ordered through an appropriate retailer who can obtain them in a few days.

Daline Units

DRIVE UNIT specified for the Daline loudspeaker (November p. 117, December p. 97) is now known as Radiospares type 163-TC.

LOUDSPEAKER PARAMETERS

I HAVE BEEN made aware by correspondence arising from the Daline articles of the belief that a loudspeaker can be scaled up or down to accommodate different size bass units—or that different bass units can be substituted in place of the specified one.

In order to prevent the inevitable disappointment that results from doing this, I wish to emphasise that this must not be done unless the designer has specifically stated otherwise.

It appears that the misconception arises from the idea that a loudspeaker is just a cabinet and that any drive unit can be installed in order to convert electrical energy into acoustic energy. On the contrary, a loudspeaker is a drive-unit working in conjunction with a 'piece' of air. The cabinet exists purely to 'mould' this piece of air and does nothing more. It is necessary to make this air match the drive unit in many ways in order to work under the required conditions.

It is by giving the air different shapes and sizes that it has different effects on the bass unit. To differentiate between these effects, the loudspeaker is given a name—acoustic suspension, reflex, transmission line, horn (and also Daline!). These titles solely describe the manner in which the air in the cabinet behaves in conjunction with the bass unit. They do not describe the size, shape or constructional details of the cabinet. If any aspects of the air loading or of the bass unit are altered, the operating conditions will be changed. If the design has been optimised, this change will be for the worst.

The cone area is only one of many parameters that a drive-unit possesses. The remainder are dynamic and require electronic test equipment to enable them to be measured. Manufacturers of units do not generally include these details in their literature, so there is no easy way of discovering them.

Different types of drive-unit with the same cone area rarely have the remaining parameters identical. Because of this it is not possible to substitute different units of the same size without upsetting the performance. Furthermore, it is incorrect to apply the illegitimate law of scaling to make a designed cabinet accommodate different size bass units.

The sad result of altering loudspeaker designs in any way without going through the proper design processes is to be landed with a speaker that has a low frequency performance inferior even to that obtained by applying the 'throw it in a box' policy.

If it is remembered that a loudspeaker cabinet is just one component in an integrated system that operates as one entity, it may help to dispel these popular misconceptions.

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PHASE AND SOUND QUALITY

Reading all those contributions on "phase effects in loudspeakers," I cannot escape from the impression that many experts do not dare to be too certain and prefer referring to the opinions of others instead. What is everybody so worried about? Undo the tweeter from your loudspeaker cabinet so that it stands off, an inch or so nearer to the listener's ear. The result is a change in phase relationship between the high- and the low frequencies, right? An inch difference in path length corresponds with something in the order of a full wavelength for a tone of, say, 10 kHz. If this is not enought phase shift, move the tweeter further, a foot or so, so that the phase tumbles several times over and over before it reaches your ear. Better still, ask somebody to move the tweeter for- and backwards for you, so that there is a continuously varying phaseshift between the high- and low-frequency components.

Why not try that on a rainy Sunday afternoon?

I did. With sounds of harpsichords, pianos, plucked strings, whole orchestras, voices, rushing water, white noise, square waves. And I eat my hat if I hear phase effects.

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Lammersdorf,
Germany.