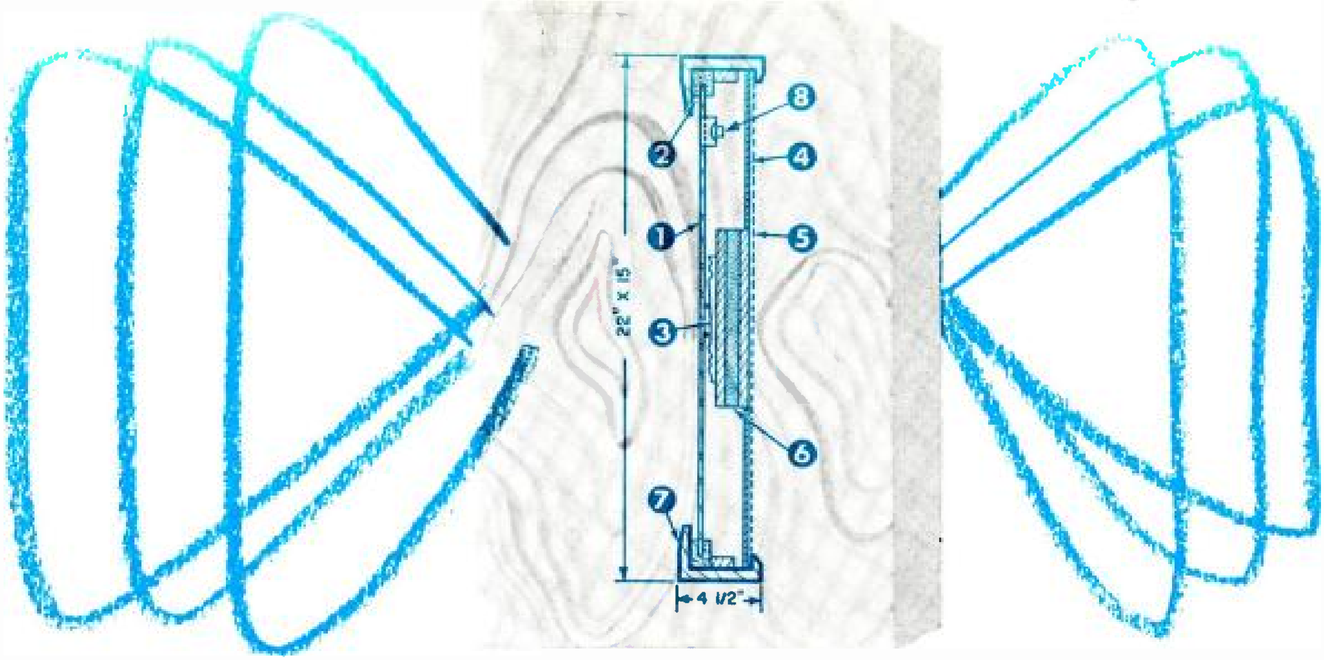

The "Bi-Phonic Coupler"

A Unique Hi-Fi Speaker System

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An unbaffled system, using a large flat wooden diaphragm rather than a small paper cone to radiate hi-fi sound, promises fewer decor problems.

LOUDSPEAKER system design has undergone a period of evolution engendered, in the main, by the progress that has been made in the design of the "heart" of the system itself—the driver unit. In the earliest days of sound reproduction the driver unit consisted of an over-powerful earphone coupled to a "morning-glory" type horn. In fact, such a system was originally called a "loudspeaking telephone," which in due time became fore-shortened to simply "loudspeaker." The morning-glory horn of the early days was not a thing of living-room beauty, but this was not a matter of great concern, for its lack of decorative merit was compensated by the fact that it made possible the technical marvel of mechanically reproduced sound.

From these early beginnings, the loudspeaker mechanism has been improved to the point where any present advance is measurable only in the "last decimal place." This is not generally true, however, for the enclosures that up to now have been as important to the proper reproduction of sound as the loudspeaker itself. In the history of enclosure design we have gone through phases involving the large flat open baffle; the large closed box approximating the infinite baffle; the horn-loaded baffle; the bass-reflex baffle; the combined rear- and front-loaded enclosure; and, most recently, the small sealed box. These systems have ranged from large, massive, wardrobe-type of cabinetry that were awe-inspiring in size (and difficult of placement), to the very small enclosures that today are lumped into "bookshelf" category or system.

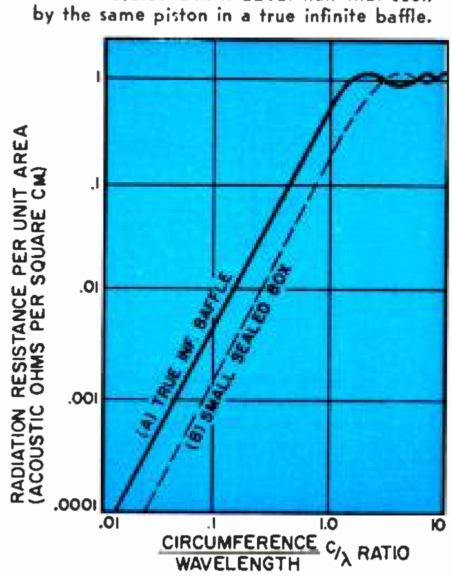
The one common characteristic of all of these systems is that, in some form or another, they are boxes that house a separate sound producer—the loudspeaker itself. These boxes must somehow be fitted into the general pattern of furniture arrangement and, because they are boxes, all have a "live" side, a "dead" back side, and must be used in such a fashion as to show their faces and hide their backs.

The loudspeaker system to be described—called the "Bi-Phonic Coupler," Fig. 2—in addition to being a radical departure from conventional design has broken through the "decor barrier." It is a *live* system in that it is not boxed. It radiates from both sides of its thin contour so that it may be placed, if desired, in the center of a room to fill the room with sound produced uniformly from both sides. Because it is thus freed from the boxed container, it is also freed from the conventional loudspeaker location areas, although it may, of course, be used in these conventional spots if desired.

Of more interest to the technical man is the way in which the very deepest of bass and breadth of sound can be obtained from a system which is so radically different from conventional loudspeakers—a system which uses no conventional cone, is completely unbaffled, and produces its sound from the vibrations of a very stiffly held wooden panel which is, literally, as "stiff as a board."

Loudspeakers generally reproduce sound by the vibrations of rigid "pistons," which are loosely suspended. In general, the cone-type loudspeaker makes use of a deep-formed molded, or folded, paper cone so that it may obtain, by this construction, some measure of rigidity while it is vibrating. Such a flexibly supported rigid cone structure vibrates and produces sound when driven by an electrical signal applied to its voice coil which is immersed in the magnetic circuit. The degree to which such a rigid piston produces sound is determined by its size and how it is baffled—a baffle signifying a device which prevents the rear wave of sound

Fig. 1. Radiation resistance seen by piston in small sealed box is about half that seen by the same piston in a true infinite baffle.



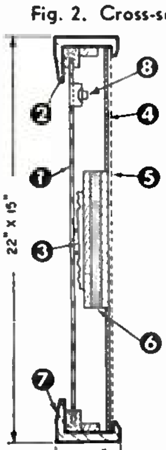
from the diaphragm from interfering with the front wave. Such a baffle, called an infinite baffle, is one which theoretically should be uniplanar with the piston surface and extends infinitely far in all directions of the plane. In actual practice, a large wall between two rooms with the piston mounted in the wall fairly well towards the *central* part of the wall very nearly constitutes an infinite baffle, for there exists complete front-to-rear isolation of the sound vibrating from both sides of the speaker. And yet, because of the large volume of the rooms involved, the loudspeaker is radiating in relatively free space on either side.

Radiation Resistance

When a vibrating piston is mounted in such an infinite baffle, its sound output, at a given frequency, is governed by the radiation resistance it "sees" at that frequency. This dependence of the radiation resistance upon piston size and applied frequency is shown graphically in Curve A of Fig. 1. It will be observed that for a given frequency (or wavelength) the radiation resistance will vary directly as the radius of the piston. Since the acoustic power that the piston can deliver is a direct function of the radiation resistance it sees, then to produce an increase in radiated power at a given frequency (for a given electrical input power) the piston radius would have to be increased. This would increase the C/λ ratio and move the radiation resistance operating point higher up on the curve. This, basically, is why a 15" speaker produces better low-frequency radiation than a 12", for example, all other controlling elements remaining unchanged.

Thus, *theoretically*, it is possible to increase the radiation resistance for a given frequency at will by going to larger and larger diaphragms with increasingly better reproduction at low frequencies. Practically, however, there are physical limitations imposed on making conventional diaphragms too large. Molded paper cones become physically unstable and do not act as true pistons when they get too large—for they begin to flex within themselves. Second, the larger they get, the deeper they must be made to maintain some measure of the mechanical stability.

Fig. 2. Cross-section of speaker system.

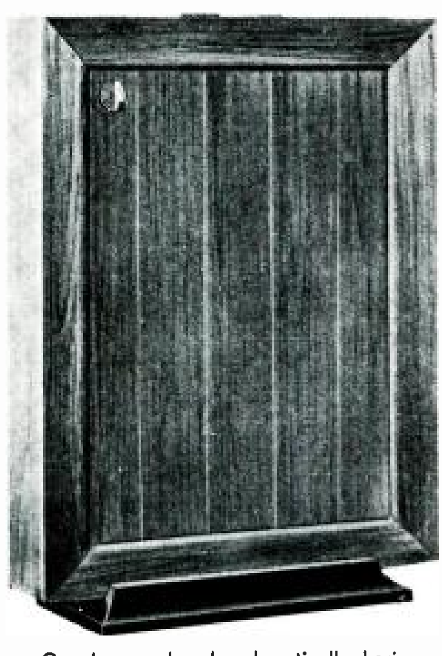


1. FLAT WOODEN FRONT RADIATOR, 22" X 15"
2. RUBBER RADIATOR SUSPENSION
3. VOICE COIL
4. DIPOLE CONTROL RESISTANCE (FIBER GLASS)
5. REAR RADIATING SURFACE (SLATTED)
6. CERAMIC-MAGNETIC STRUCTURE
7. SUPPORTING FRAME
8. TWEETER

Furthermore, with its accompanying magnet structure, the large size cone-type speaker becomes excessively large and deep necessitating an even larger and deeper box-type enclosure in which to house the speaker—whose function it will be to baffle the rear-radiated wave from the front.

Curves are given in the literature which indicate that for a true infinite baffle, the radiation resistance, as seen by the piston mounted in that baffle, is approximately twice the value of the radiation resistance for the same in a small sealed box; usually smaller than 8 cubic feet (Curve B, Fig. 1). The reason for this is that although the small sealed box may prevent front-to-rear wave cancellation, the piston does not "see" the large, flat, infinitely extended baffle plane. Instead, the radiation diffracts around the small box edges and thereby loses some of its forward projection radiation. The small box radiates into "full acoustic space" of 4π steradians while the true infinite baffle radiates into "half space" of 2π steradians, with, of course, an attendant power gain when it thus radiates into only half the volume of the small box. Thus, simply sealing the back end of a piston in a box does not necessarily result in optimum acoustic coupling to space.

Now, let us consider the situation which would arise were we to free our-



Coupler may be placed vertically, horizontally, or even hung directly on wall.

selves from the baffle entirely. Again, we look to the established literature and find that there is a curve of radiation resistance of a piston radiating without aid of a baffle at all. This curve (Fig. 3) merely verifies what we have learned from everyday practice, namely, that for a *given* size piston radiating at a *given* frequency, radiation efficiency will be greater when baffled than when unbaffled. Thus, for instance, if the piston is sealed off and operating at some frequency such that the ratio of piston circumference to wavelength is 0.35 (as in Fig. 3A), then the radiation resistance will be 0.015 acoustic ohms per cm^2. However, for the same piston unbaffled, operating at the same frequency, the radiation resistance drops to .0001. This effect simply leads to the well-known conclusion that when unbaffled the piston will not produce as much low-frequency power as when baffled.

Unbaffled Piston

However, there is another way of looking at this relationship whereby it will be possible to realize as much power from an unbaffled piston as from a baffled one. Using the same relationships, we are going *to choose a radiation efficiency level that we might expect from a boxed piston operating at a given frequency and find what size unbaffled piston will correspond to the same radiation resistance level.* Thus, for a given level of radiation, we simply move horizontally from the baffled curve to the unbaffled curve and can now find a different circumference-to-wavelength ratio for the unbaffled piston which will produce the same radiation output as the small baffled piston ratio of piston circumference to the same wavelength. From Fig. 3B, it will be seen that for a radiation resistance of .0015 for a C/λ of .1 (small box condition), we move horizontally to the unbaffled curve and find a value close to .5. Since, however, we are maintaining the wavelength, λ, constant, then the circumference of the *unbaffled* piston will have to be approximately five times as large as the baffled one to produce the same power output at that given frequency. Thus, by simply choosing the right size radiator, we may *theoretically* reproduce, by means of an unbaffled piston, any desired low-frequency power equivalent to that of a considerably smaller *boxed* piston.

However, for purposes of adaptability to home use, a piston size of 15" x 22" was chosen and even this size is not too critical. For example, if we use the figure of .0015 radiation resistance level for a circumference-to-wavelength ratio of .1 for a baffled piston and move horizontally to some intermediate value of C/λ such as .4, which for a fixed frequency means a piston four times as large as the baffled one, then we find that we are *almost, but not directly* on the curve representing an unbaffled piston. At this point of C/λ equal to .4, which represents an *almost unbaffled piston* condition, we may expect the same level of radiation as a baffled piston of one quarter its size.

Now the expression "almost unbaffled" may seem paradoxical. This is actually only a matter of semantics for what we mean by a closed box is really a device that prevents the rear wave of the speaker from coming around to the front. Actually, then, the phrase "somewhere between a closed box and an unbaffled piston" may be restated as "at some condition of radiation where *part* of the rear wave is kept from interfering with the front wave." With this in-

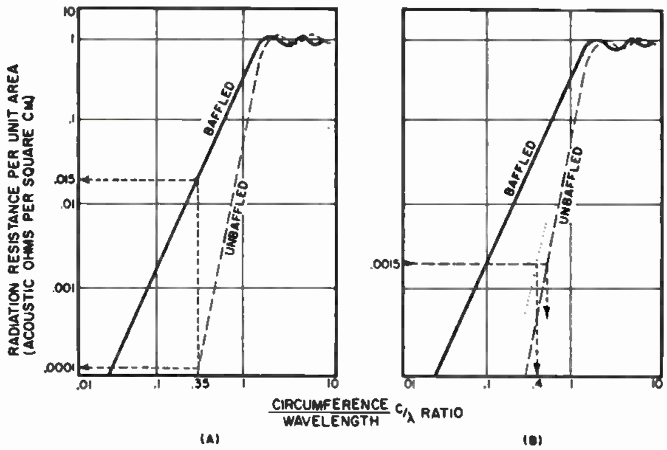


Fig. 3. (A) For a given wavelength, a fixed size piston will produce much less low-frequency power when unbaffled than when baffled. (B) However, for a given radiation level and for a given wavelength, a large unbaffled piston size may be obtained to produce the same low-frequency power as a smaller piston when in a closed box.

terpretation, it becomes fairly easy to provide the necessary control of the radiation from the back side so that the piston will operate on the intermediary characteristic indicated on the graph.

The rear-wave control is actually a combination of acoustic resistance material and an aperture screen which, together, provide just the right attenuation of the rear radiation to allow the free piston to produce the necessary output power without aid of conventional baffling. By actual measurement the rear attenuation is very small, so small in fact that only accurately calibrated measuring instruments can detect the difference in level between front and rear radiation—the ear certainly cannot hear the difference. In brief, then, by selecting a comparatively large piston and judiciously controlling the rear radiation through a *small* measure of acoustic resistance, it is possible to achieve, from the essentially *unbaffled* piston, low-frequency performance equivalent to that obtained from small pistons in sealed boxes.

Because the piston is essentially unbaffled, it performs as a dipole radiator, *i.e.*, each side acts as a radiator of acoustic energy. As a dipole radiator, the spatial distribution of the sound coming from the radiator is a "figure-8" pattern (Fig. 4), that is, there is one lobe of radiation from one side and another lobe of radiation from the other. Such spatial distribution differs considerably from that of a piston in a closed box from which the radiation is generally hemispherical for the low frequencies. For the dipole radiator, then, low-frequency orientation is more directionally positive—which is of special value in stereo reproduction. In conventional boxed systems, the diffusion of the lows throughout the room makes stereo orientation of the lows difficult but with the dipolar directivity of the unbaffled piston, this low-frequency ambiguity is eliminated.

Mechanical Problems

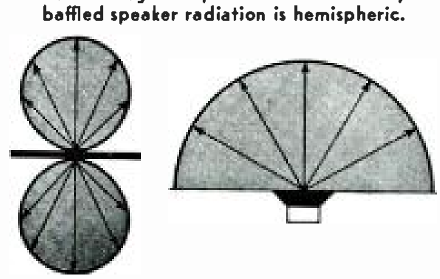
In order to provide the necessary piston action for the large radiation surface and still keep the structure flat, special methods had to be developed to obtain the necessary combination of rigidity and compliance of the panel. This was accomplished by using light, yet rigid, wood sections cemented together and braced in the rear with strategically spaced wooden members. This provides not only the necessary rigidity to the panel but is also effective in adjusting the acoustic response of the system.

Since the entire structure is made of wood, the problem was made more complicated by the fact that a single large panel of wood would not be of uniform density, nor of uniform flexure characteristics. In order to overcome this problem, the piston panel is made of five strips of selected woods—each strip having the same density and elasticity. Once these individual strips have been selected for uniformity and density, they are ready for assembly.

The type of glue or cement used is of extreme importance in maintaining vibrational strength of the panel. Simple cabinetry types of glue are not suitable in that they are essentially hard and brittle and would be shattered by the violent (although small) vibrations of the piston. Yet, on the other hand, it is not possible to use very flexible glues that would not shatter since these flexible glues would not provide the proper adhesion of the panels to provide the controlled piston action required. Accordingly, the adhesive material adopted was a specially devised combination of both thermoplastic and thermosetting types.

Once the panel had been assembled and tested, it was found to contain undesirable, although not excessive valleys and peaks. To eliminate these irregularities, it was found necessary to brace the back of the piston with strategically placed struts and mass damping elements which smoothed out the response characteristic of the piston panel. Because the wooden panel and its necessary bracing involved considerable weight (approximately 185 grams) its means of suspension became one of great stiffness, even to resonate at 20 cps. In fact, the suspension turned out to be more of a rigid clamp than a flexible support. To prevent undue mechanical noises from the piston vibrating against its clamp, a soft, compressed rubber seat which grips the piston under pressure was incorporated, allowing it to flex in this tight grip without vibrating against hard, noise-producing surfaces. Actually, this design has eliminated the flexible support of the conventional speaker cone with its attendant edge-resonance effect and structural fragility.

Fig. 4. The unbaffled piston (left) produces a figure-8 pattern while ordinary baffled speaker radiation is hemispheric.



Because the piston is so rigidly supported, there is minimum excursion of the piston as a whole which permits the voice coil, which is attached to the piston, to be practically completely linked with the magnetic gap of the circuit. In this structure, where the voice coil is so completely linked with the gap, high electrical efficiency can be obtained with magnetic non-linearity reduced to a minimum because of the practically immobile large diaphragm. High electrical efficiency invariably leads to high electrical damping, both of which together produce the conditions for excellent transient response characteristics. Moreover, the large (15" x 22") piston itself sees a high radiation resistance which is true radiation damping—effective in producing good transient response.

While the piston is, by itself, a wide-range reproducer, it was felt that seasoned audiophiles would prefer a little more highs so a tweeter was incorporated in the system. The tweeter is a high-efficiency, driver-type unit in which the radiating surface is a molded phenolic dome-type diaphragm. It is only slightly horn-loaded and has a phase-equalizing button for extending the very top range of the system. The network used is a simple high-pass filter. No effort was made to eliminate the high frequencies from the woofer section. This has two effects. First, by routing some of the high-frequency power to the woofer, there is a better balance of level between the tweeter and woofer section and, second, the middle- and high-frequency power radiated by the woofer, which comes from a comparatively large surface, minimizes the pinpoint effect of the usual tweeter radiation.

Decor and Applications

Let us now discuss some of the possibilities of decor and application inherent in this design. Instead of a cloth-covered box, the audiophile can now work with a furniture-finished, panelled structure which is decorative from both sides and whose sound is not radiated through, or impeded by, a grille cloth. Because it is so thin (4½"), it may be hung on the wall very much as a picture might be. In fact, there have been a number of inquiries regarding the possibility of painting a picture on the surface of the panel so that it would

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