

Some reflections on sound reproduction for the home

by

Harold N. Beveridge

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FORWARD [1]

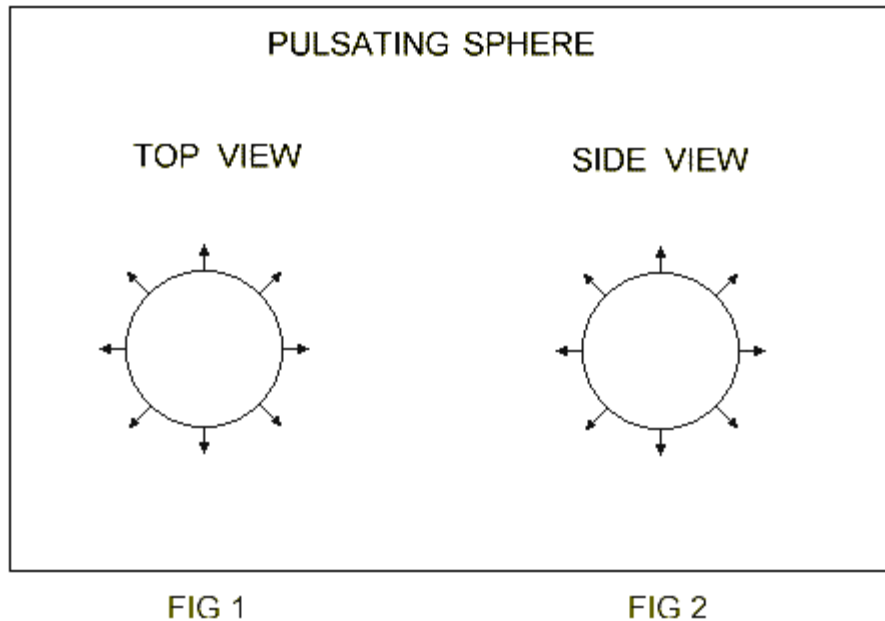
This treatise is a presentation on the subject of sound reproduction for the home, taken from the development of several original theories regarding sonic propagation. It's proscribed allowing the reader to "visualize" the points being made. The major part of this article deals with several types of sound generating devices designed for the home, and their interaction with the room. Limitations to speaker sound quality are discussed and presented both in term of physical and audible perception.

Human hearing is a remarkable process. About eight octaves of frequency are covered and in some regions sensitivity approaches thermal noise. The brain operates on all this information utilizing the geometry of the outer ear and the head. Sound coming from in front of a person can be localized to within 2° horizontally and 4° vertically. This is accomplished within about the ten milliseconds of sound arrival. Much that is in these notes relates to this very important first arrival signal.



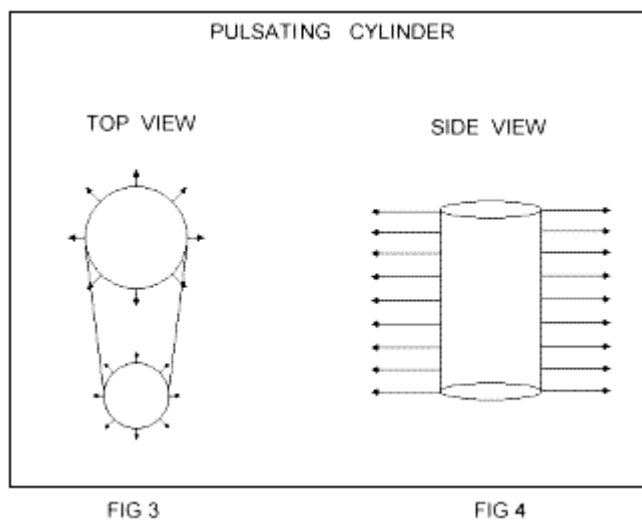
Confusion in the hearing process occurs when the same sound arrives from two closely spaced sources, but with path lengths differing by up to two milliseconds. Presumably, this is the intermediate region when ears and brain don't know whether to treat the result as a single or double signal. In any case confusion – at times intense – occurs. It is both unpleasant and fatiguing. More attention is being given to the phasing of the several discrete sources used in conventional speakers, resulting in some improvement.

In this discussion of speakers and rooms it is assumed that for practical reasons equipment should not intrude too far into a room and placement generally should be near or against a wall. Now let's look at the speaker-room problem in broad terms.



An intriguing concept, figures 1 & 2, is that of a pulsating sphere with sound radiating from it uniformly in all directions and at all frequencies. This behaves exactly like a point source. An optical analogy is a small light bulb.

Another concept, shown in figures 3 & 4, is that of a tall pulsating cylinder radiating only horizontally and uniformly at all frequencies. This is called a line source, in contrast to a point source. The optical analogy of this is a single tall vertical fluorescent tube.



There are significant differences in the way sound energy varies with distance from a point source and a line source. From a point source, sound energy spreads both horizontally and vertically. From a vertical line source, sound spreads only horizontally. The wave front from a pulsating sphere is spherical in shape, whereas the wave front that spreads out from a long pulsating cylinder is cylindrical in shape.

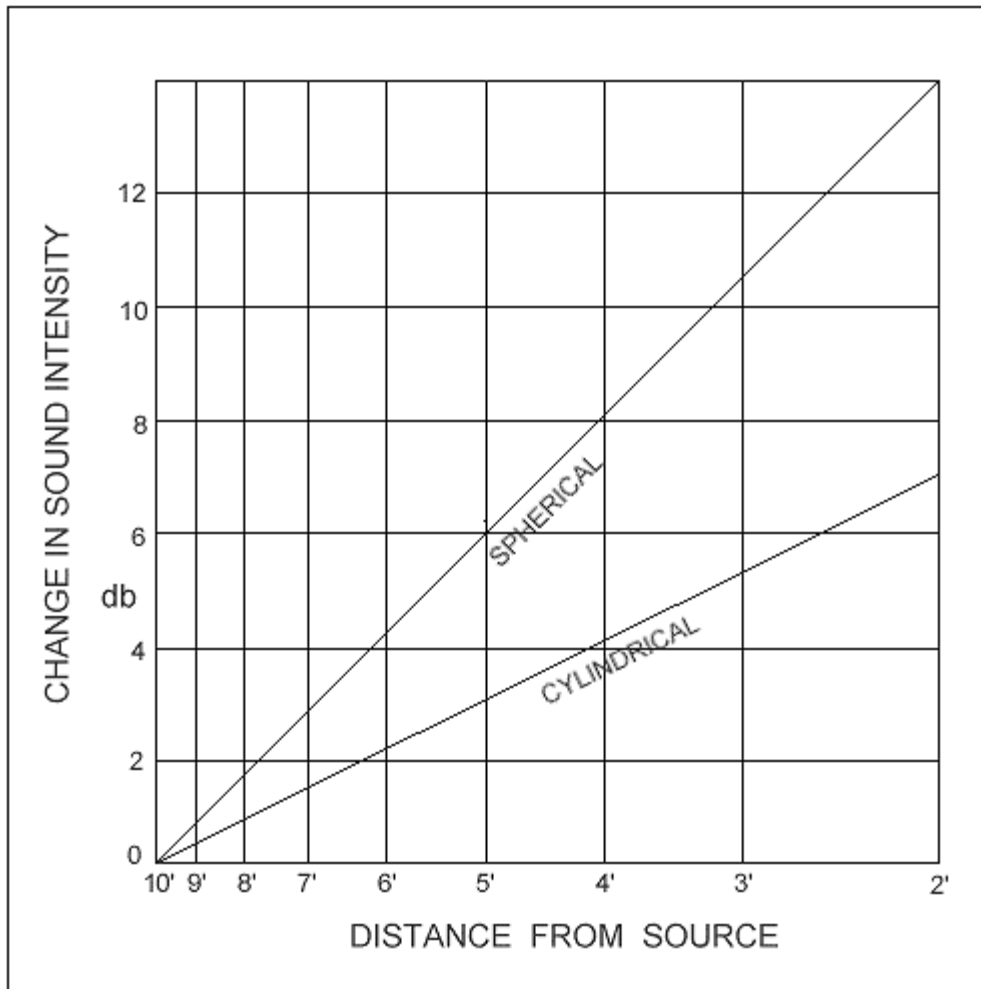
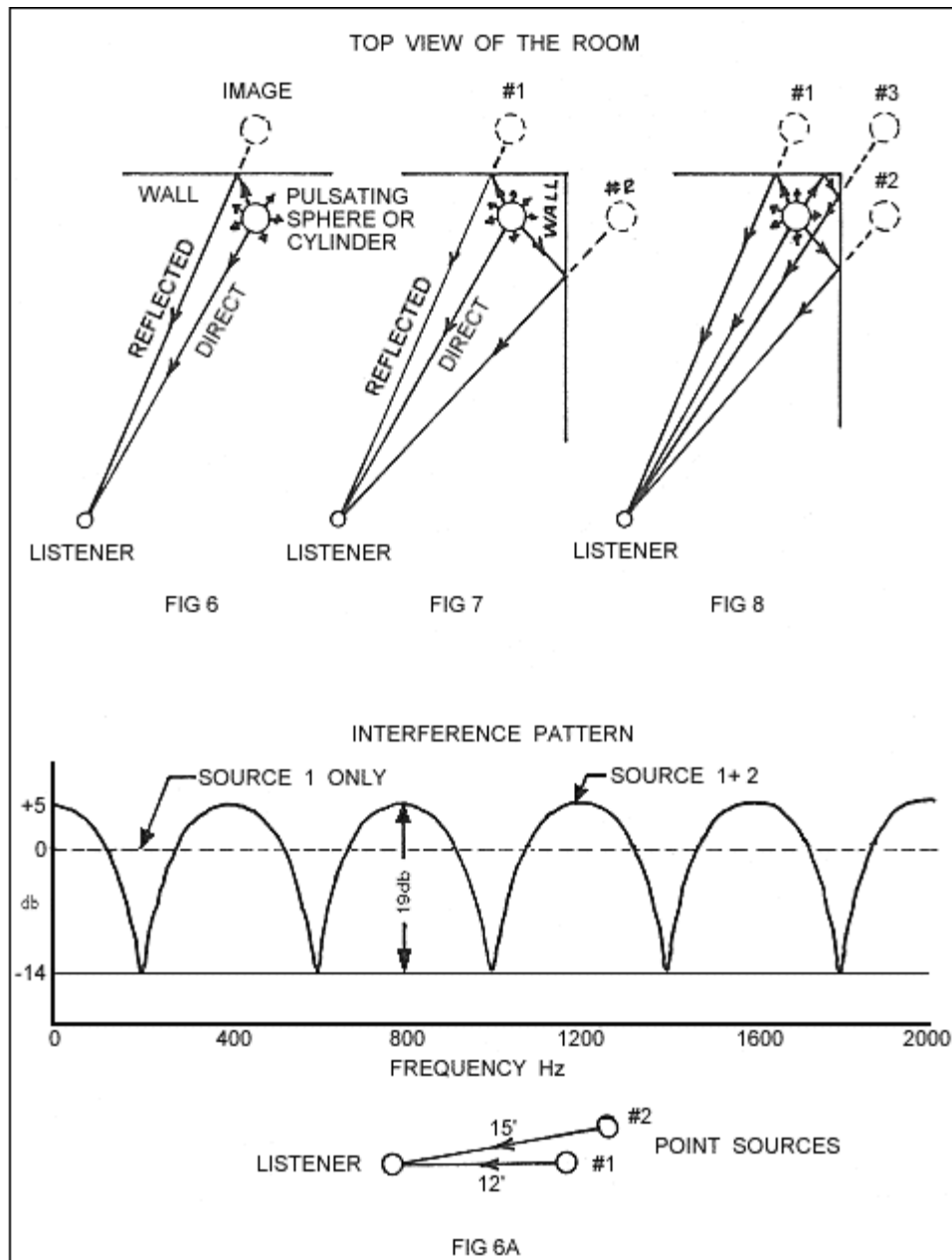


FIG 5

Note that in figure 5 above, for a given change in distance, the cylindrical wave form changes in intensity only half as much as does the spherical. Thus, the sound intensity throughout a room is considerably more uniform using a tall cylindrical source rather than a spherical source. Incidentally, typical enclosures as large as 2' or 3' maximum dimensions still behave as point sources.

Now let's study room effects with these devices. If placed near a wall as in figure 6, sound first reaches the listener via the direct path. Shortly thereafter, sound also reaches the listener indirectly via a reflected path off the wall. This reflected sound is exactly like the direct sound and of nearly equal intensity. It is convenient to think of the reflected sound as originating from an image behind the wall, just as you see your face in a mirror as far behind the mirror as you are in front. When the difference in path lengths between the direct and reflected sound (or, if you prefer, direct source and image) is less than several feet, confusion arises in the hearing process. A person cannot sense direction and the sound becomes blurred and defocused.

No thoughtful engineer would consider placing two loudspeakers in the configuration of source and image shown in figure 6. He would immediately recognize the resultant interference pattern, as in figure 6A. Yet this is just what happens when a 360° device is placed near a wall.



In figure 7 we have introduced another wall by placing the primary sound source in the corner of the room. Notice that the reflection from this wall (remember the mirror) has produced a second image. Figure 8 illustrates the full picture as we add one more image, number three. We now have a very busy corner; one pulsating source and three images imitating it. This adds up to total audio confusion.

In the case of the pulsating sphere there are reflections from both floor and ceiling as shown in figure 9 below, resulting in two more images; a total of five, for a corner location.

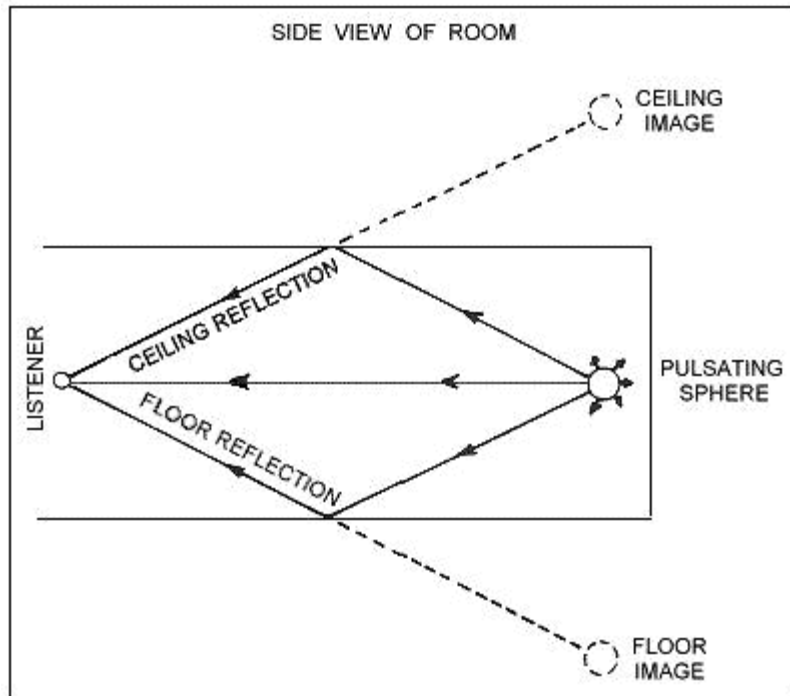


FIG 9

Surely a point source of sound, such as a pulsating sphere, placed in the corner of a room, must be the worst configuration imaginable. A tall pulsating cylinder, figure 10 below, radiates sound energy only horizontally, so there are no reflections or images from floor or ceiling.

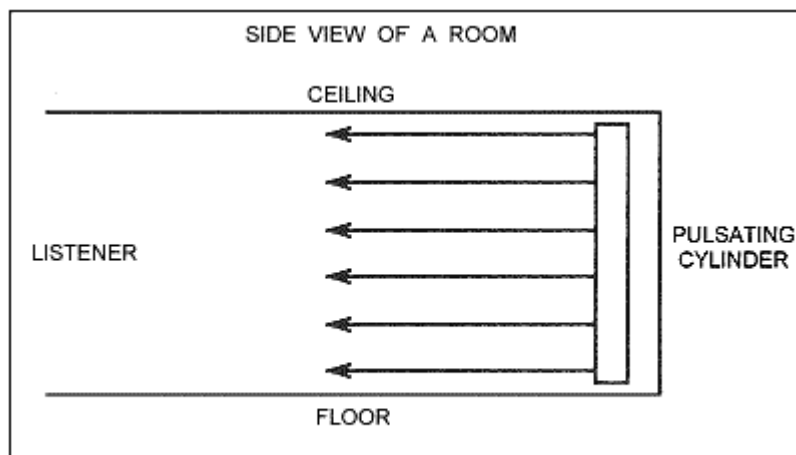


FIG 10

Figure 11 below shows a tall bi-directional screen-type speaker placed parallel to a wall. Again an undesirable image is produced. If the difference in path lengths is less than several feet, confused sound results.

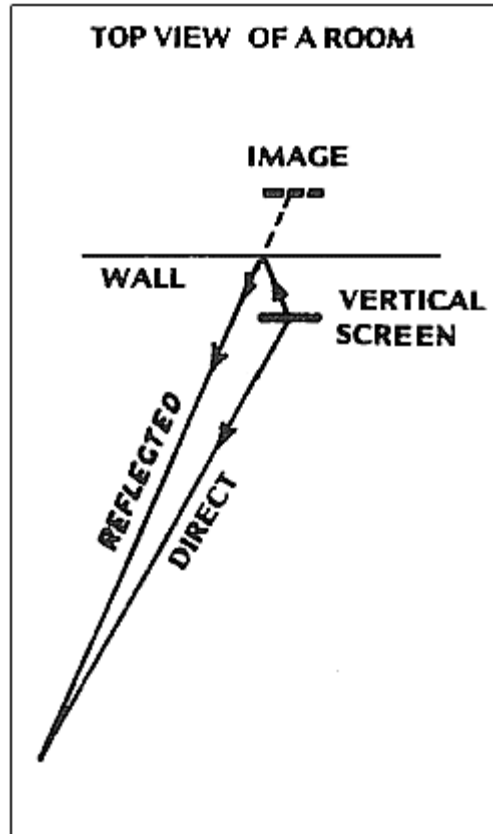


FIG 11

Another wall is introduced in figure 12. The corner produces two or three sizeable images irrespective of whether the screen is parallel to or at an angle to the back wall.

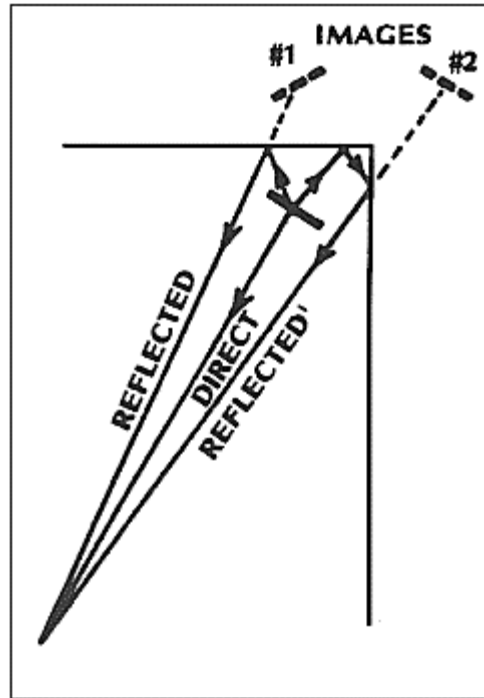


FIG 12

However, there isn't much reflection from floor and ceiling. Systems that emit sound from both front and back placed near a wall always set up undesirable images and the reflected energy produces confusion, blurring, and lack of definition.

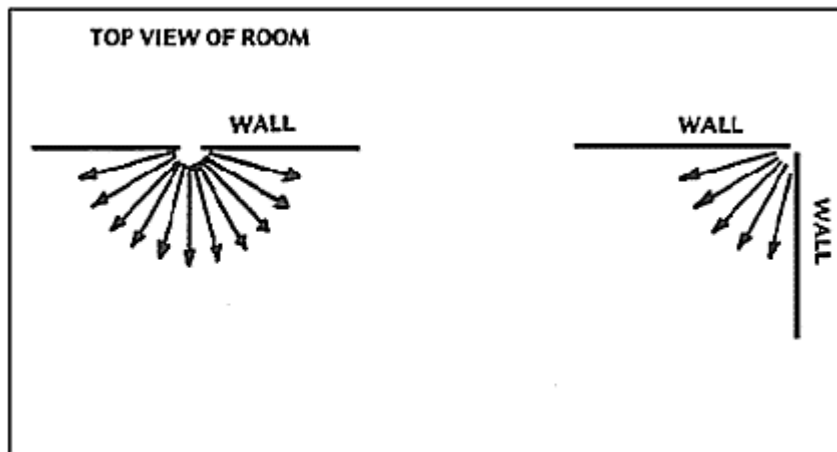


FIG 13

FIG 14

Sound introduced through a small hole in a wall, figure 13 above, would spread horizontally with great uniformity and no wall image would appear. However, the same floor and ceiling reflections shown in figure 9 would occur. Similarly, sound admitted through a small hole in a corner, figure 14, would spread uniformly from the corner but floor and ceiling reflections would still occur. Now, let us see if we can combine the good characteristics of figures 10 & 13. The horizontal projection of sound as in figure 10 with no floor or ceiling images is to be desired.

Also desirable is the uniform spread of sound over a full 180 degrees with no wall images as in figure 13. How do we combine these?

If energy enters the room as shown in figure 15 through a floor-to-ceiling narrow slot in the wall, or an equivalent, the sound spreads horizontally over 180 degrees at both floor and ceiling levels and everywhere in between, but does not spread up or down.

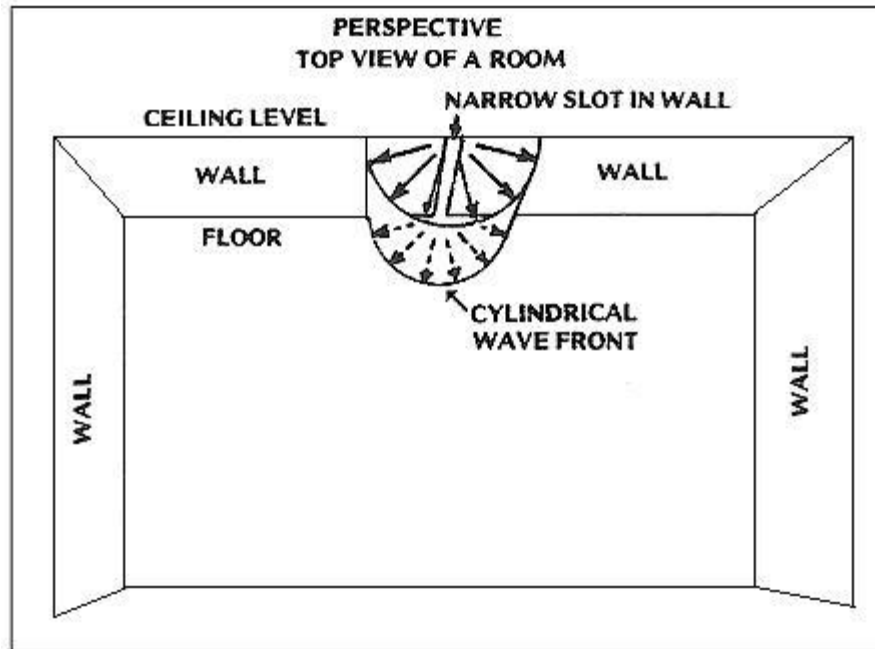


FIG.15

This we call a cylindrical wave front. Coverage is from floor to ceiling and wall to wall. There are no unilluminated areas in the room. Figure 16 below shows two cylindrical wave generators, one on either side of a room. No near reflections occur to produce sound confusion.

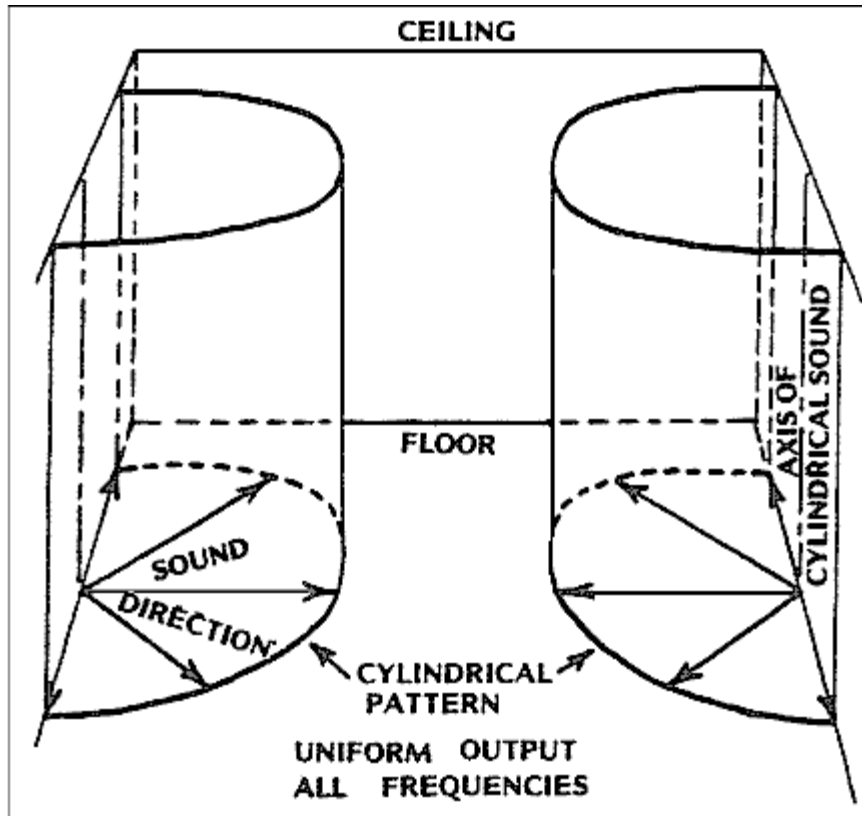


FIG 16

Contrast the foregoing with the usual placement and behavior of conventional loudspeakers above in figure 17 below.

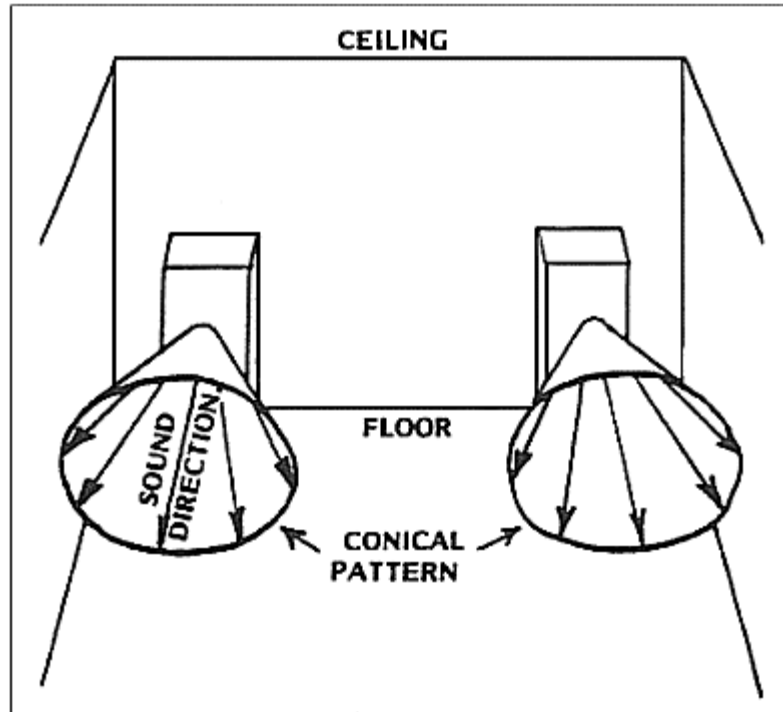


FIG 17

No accurate drawing can be made to illustrate how sound spreads from such a source. The conical pattern illustrates the limited solid angle of high frequencies; at mid-frequencies, the cone of coverage is much wider, and at low frequencies energy spreads evenly in all directions from the enclosure. Thus, there is distortion of the frequency response over much of the room. The frequency response can not be correct in front of the speaker and also to the sides. It can not be correct on-axis and off-axis. Reflections from floor and ceiling and sometimes walls, delayed only slightly may confuse the sound.

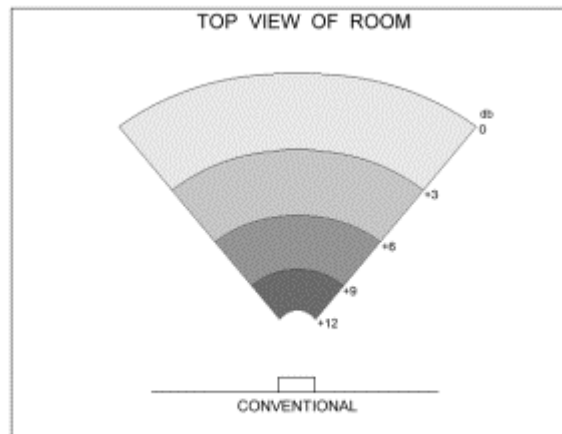


FIG 18

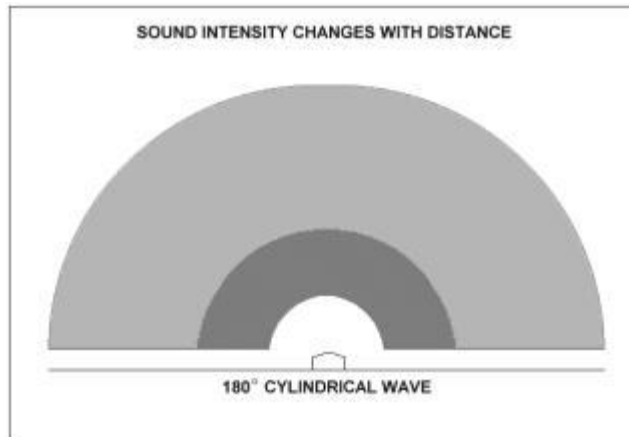


FIG 19

Figures 18 & 19 show the differences in the extent of room illumination provided by most conventional systems, and that provided by a cylindrical wave system. The outermost band in each figure shows the radial distance for a 3 db change in sound intensity. A cylindrical wave system has about twice the radial extent of the conventional system.

Let's next think about angular coverage. Typical conventional systems provide perhaps 60 degrees of horizontal coverage at the high frequencies. Outside this limited region frequency response distortion occurs and may be severe. Figure 19, in contrast, shows how a 180 degree cylindrical wave system provides uniform frequency response from wall to wall. The total area of the room thus covered - depth and angle - is about five times greater for the cylindrical system compared with conventional systems.

Figures 6, 7, 8, 11 & 12 demonstrate the placement problems of 360 degree and bi-directive devices. Having a high frequency coverage of 60 degrees or less limits the placement of most conventional speakers to that shown in figure 17.

It is our opinion that a vertical line source with a horizontal dispersion of 180 degrees is the optimum design. A new placement technique is illustrated in figure 20 (also in Fig.16). Such placement is not feasible with conventional units because of limited horizontal dispersion.

Now let's look at figures 20 & 21 carefully. The direct path of energy from speaker to listener is obvious and there are no near images.

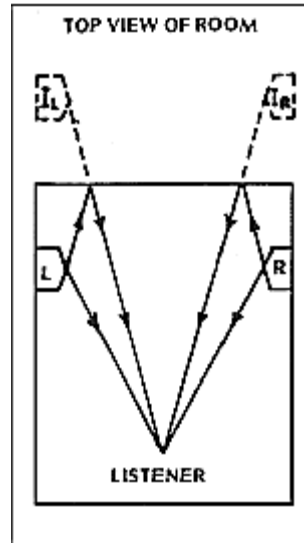


FIG 20

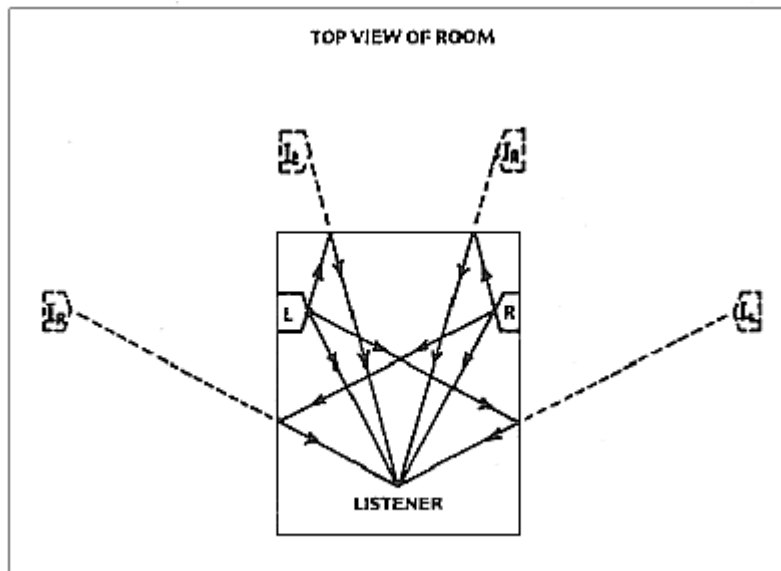


FIG 21

Three important points need to be made. First, these full frequency range reflections are identical in form to the direct path sound. Second, they are nearly as intense as the direct path. Third, the delay in these paths is easily made large enough to avoid confusion and the ear accepts them as normal room reflection. This adds spaciousness and depth to the sound.

In stereo an exact and precise "image" of the orchestra is desired: violins on left, cello and bass on right, and so on. Such an image is best produced when at least 10 milliseconds of the first-arrival energy is delivered to the listener with no overlap of sound from image speakers to produce confusion. 180 degree cylindrical wave speakers meet this criterion. No near reflection paths are present and no near image speakers appear. All four image speakers are far enough away from the primary speakers for a clear and unencumbered packet of first-arrival energy to be perceived. A precise stereo image is formed.

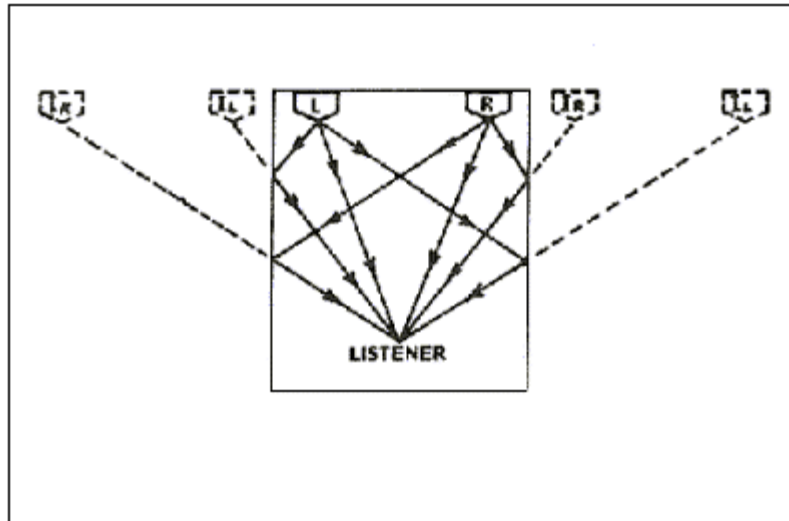


FIG 22

Two cylindrical wave speakers are shown in figure 22, both placed on one end wall of a room and close to a corner. Note that the image path is not much longer than the direct. This placement is, therefore, less desirable than that shown in figure 21.

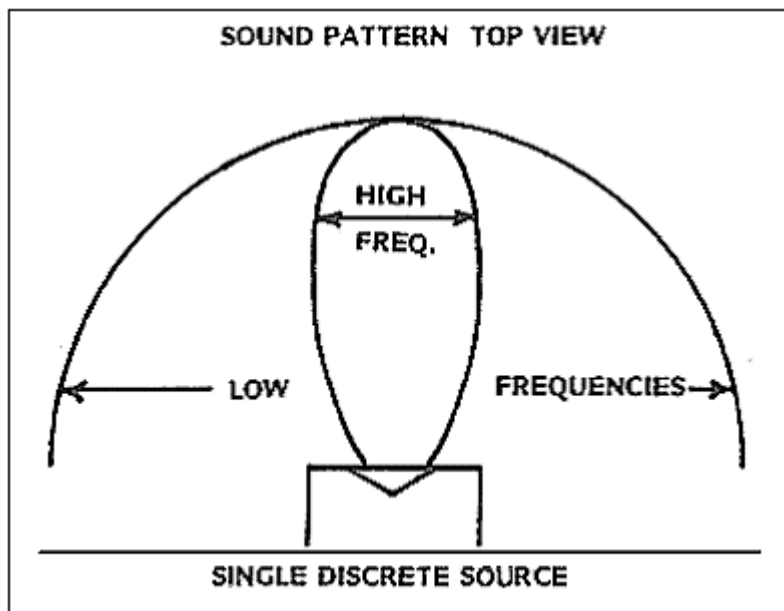


FIG 23

Figure 23 shows a simple conventional speaker. The major drawback to such a speaker is its inability to cover the entire audio frequency and its poor dispersion at high frequencies. A common way to lessen these limitations is to use two driver units: one for high frequencies and one for low, as shown in figure 24 below.

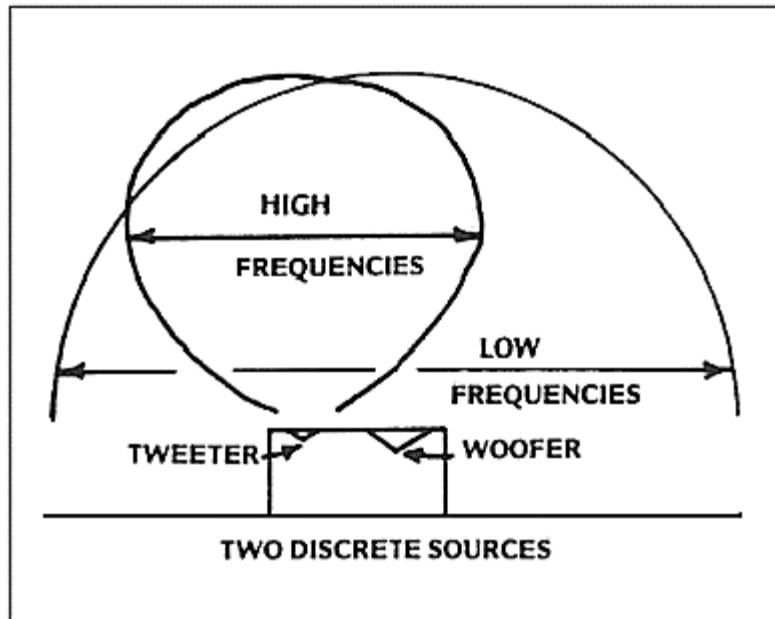


FIG 24

However, when listening off-axis horizontally, figure 25 below, which is often the case, there is a delay distance between the two units, degrading the sound quality.

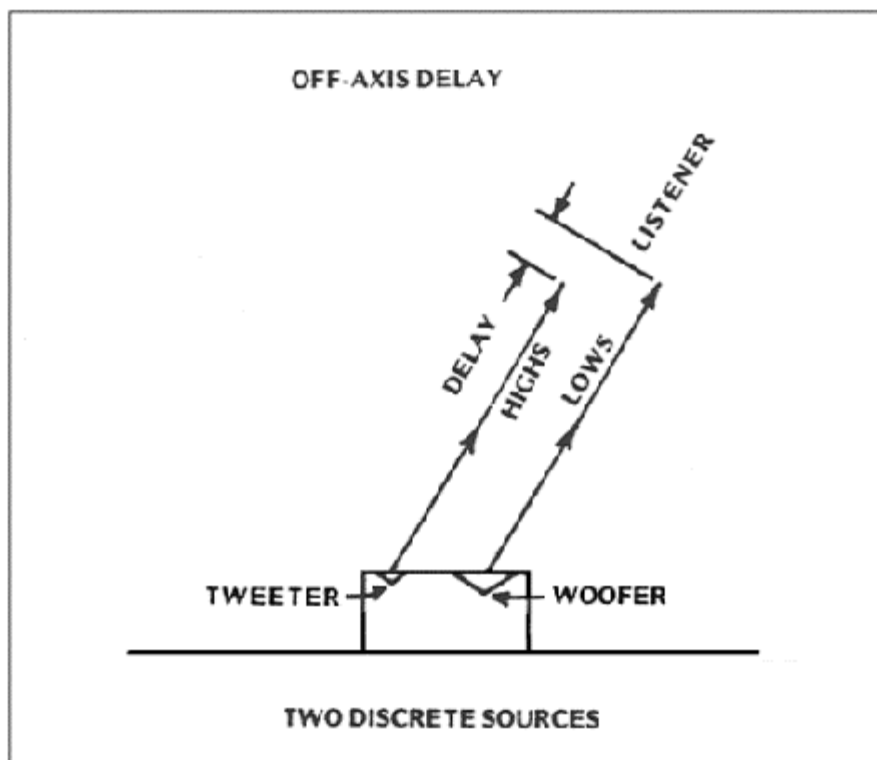


FIG 25

If tweeter and woofer are mounted one above the other, the horizontal off-axis problem is replaced by a problem in the vertical plane. Frequently, more than two discrete units are used in expensive speakers for the home - perhaps, three or six or eight or more. It is clear that off-axis, various delay distances are bound to occur and the transient response of such arrangements can not be very good. Electrical cross-over networks impose still further limitations on exact reproduction.

Figure 26 shows the behavior of bi-directive (open back) systems – screens. Note that the back wave washes around and mixes with the forward wave, although delayed somewhat.

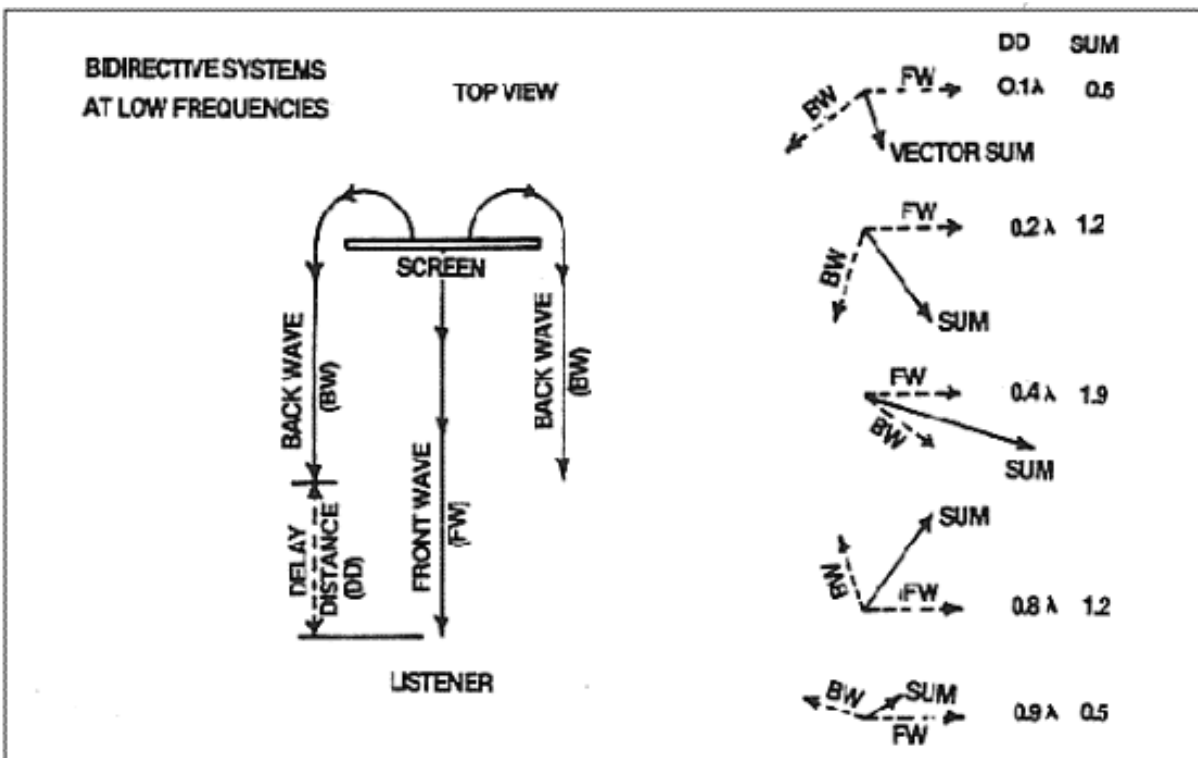


FIG 26

At very low frequencies - long wave lengths of 5' to 10' - this out-of-phase back wave largely cancels the front wave and bass output is poor - see top vector diagram. At a somewhat shorter wave length, these two waves add to produce excessive output - third vector diagram. At still higher frequencies (shorter wave lengths), the sum of the two waves gets small again - bottom vector diagram. This unevenness can produce a tubby sounding bass. To avoid this problem most loudspeakers use an airtight enclosure to eliminate the back wave. Eventually, at higher frequencies, the back wave begins to beam and this effect becomes negligible.

Now let's review the significant considerations for an optimum loudspeaker system.

1. A pulsating sphere or pulsating 360 degree cylinder, or a screen, creates image problems whenever placed near a wall or corner (Figs. 1 - 4 and 6 - 12). Additionally, at low frequencies, bi-directive screens are subject to interference problems which degrade frequency response.
2. Small boxes, 3' or less (Fig. 5) radiate as point sources and consequently sound intensity with distance changes twice as much as with tall devices (nearly floor to ceiling) - (Fig. 10).

3. While the hole-in-the-wall concept of figures 13 & 14 eliminates wall reflections, the drawbacks of floor and ceiling reflections and rapid change of sound intensity with distance make this option unattractive.
4. The narrow slot-in-the-wall concept of figures 15 & 16 has these advantages: no near image problems (Figs. 20 & 21); total room illumination with uniform frequency response (Fig. 16); minimum sound intensity variations with distance (Figs. 5 & 19); no off-axis delay problems (Fig. 25); and no back wave problems (Fig.26)

Can we implement the narrow vertical slot-in-the-wall concept? All we really need to do is generate a full frequency range, floor-to-ceiling, cylindrical wave 180 degrees wide as in figure 15. The **Beveridge Cylindrical Sound System** accomplishes this. A cross-section of the unit is shown in figure 27.

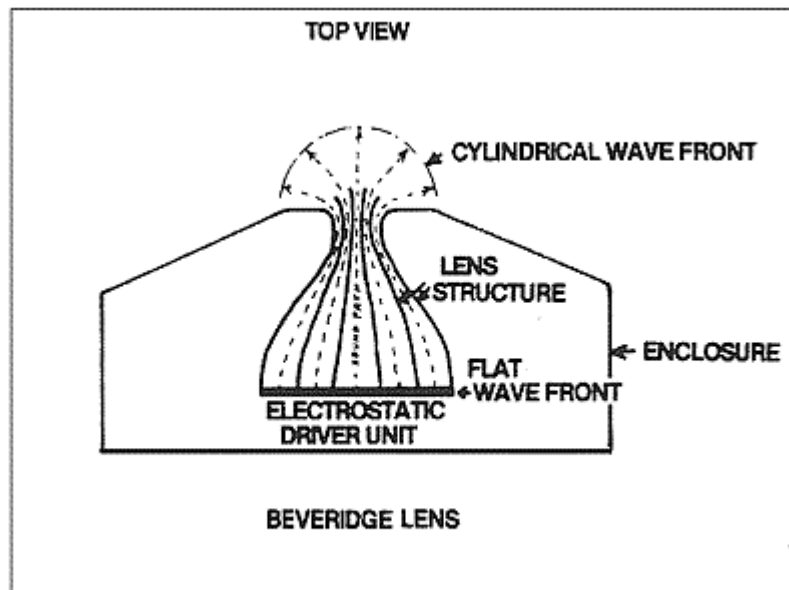


FIG 27

Description and specifications are given at the end of the article and photographs are included [2]. A patented electrostatic driver 6' tall produces over the entire audio range a very high quality plane wave front, which enters the 6' high patented Beveridge lens structure. This consists of vertical guiding walls as illustrated. The sound follows the path shown by the dotted lines and emerges in a 180° cylindrical sound front covering the entire audio spectrum. The back wave is absorbed in the enclosure.

This loudspeaker has a radiation pattern that is invariant with frequency. The transient response of the system is unsurpassed.

[1] Diagrams starting at Fig.6 onward are original Harold Beveridge drawings.
 [2] See [A Beveridge Pictorial Legacy](#).