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MULTIPLE-LOUDSPEAKER SYSTEM

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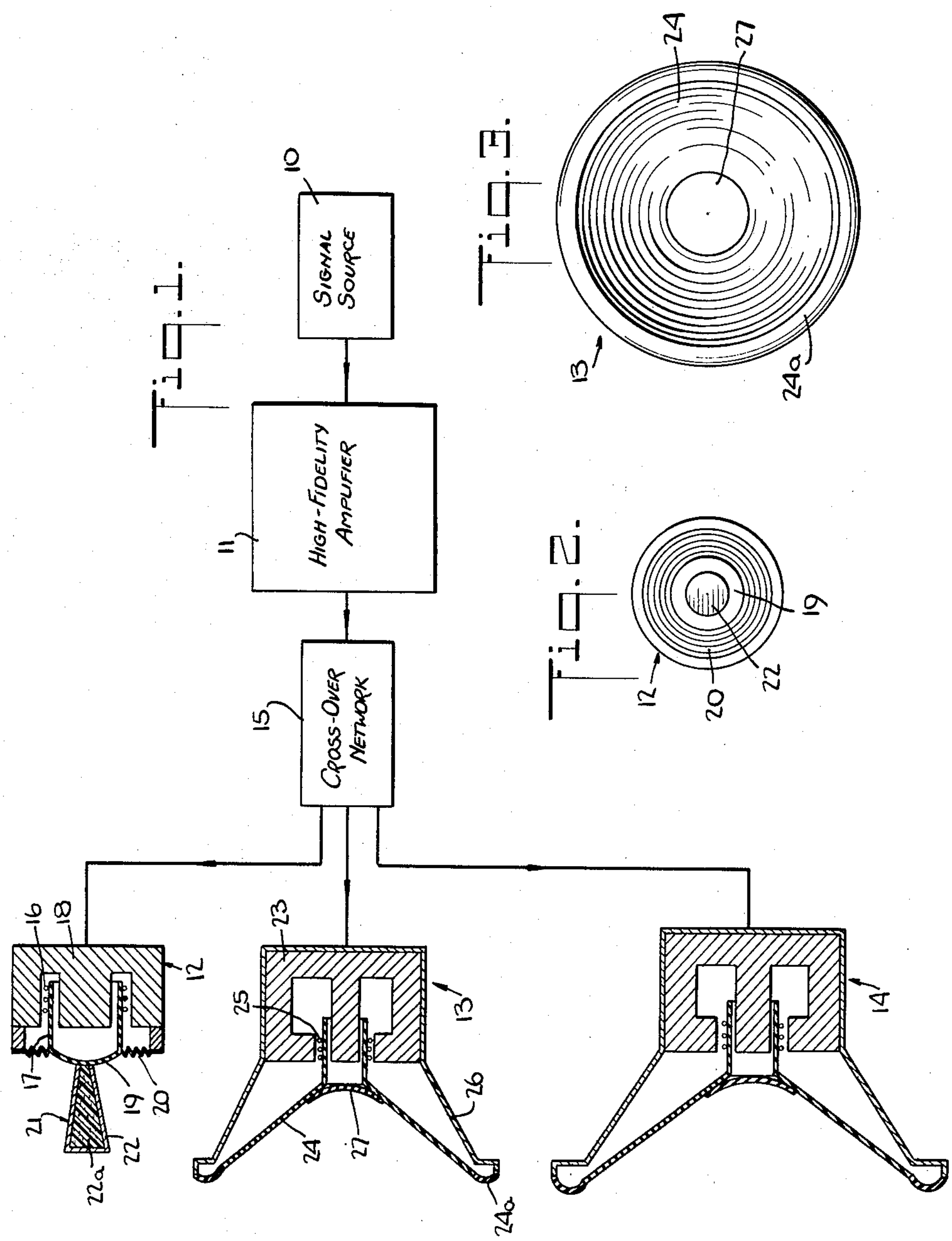

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Fig. 4.

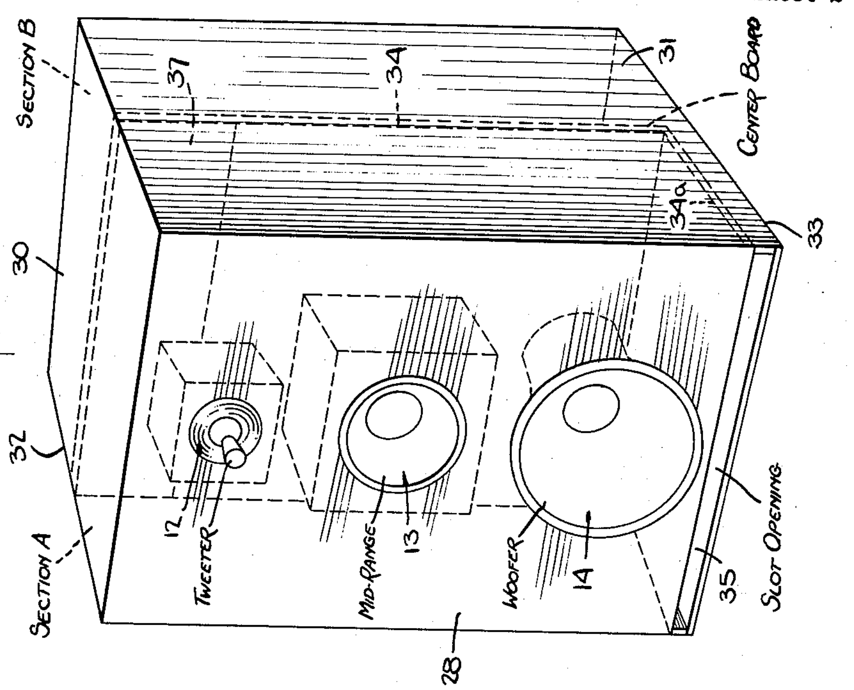
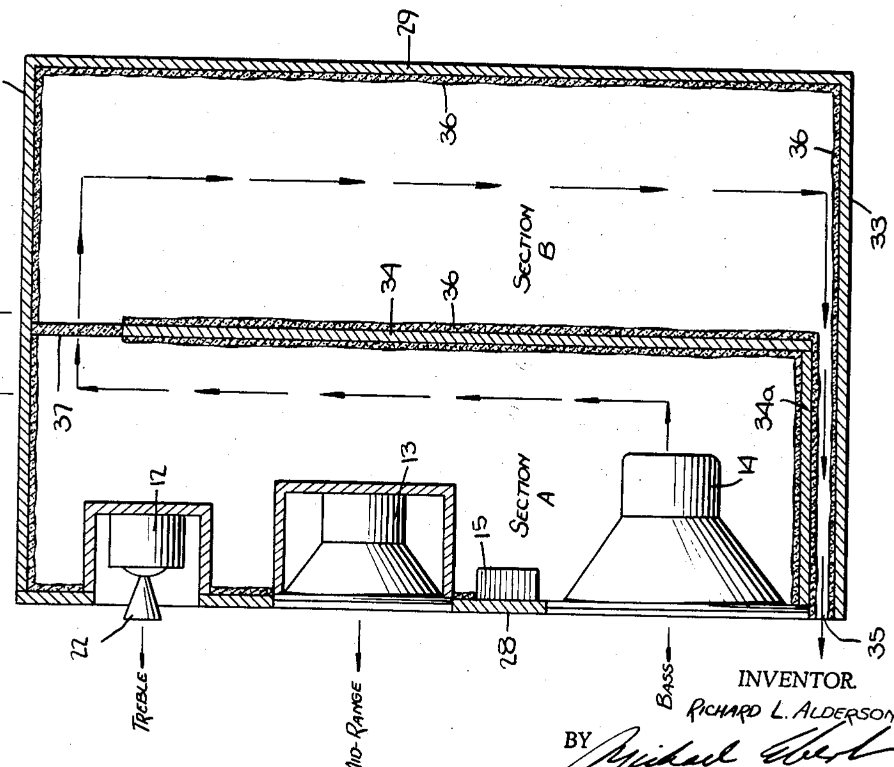


Fig. 5.



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MULTIPLE-LOUDSPEAKER SYSTEM

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This invention relates generally to audio reproduction techniques, and more particularly to an integrated, multiple-speaker acoustic system whose enclosed units smoothly cover complementary frequency ranges without cross interference therebetween.

In recent years, engineering developments have greatly expanded the frequency range in which it is possible to record, amplify, transmit and reproduce audio signals. Modern tape, film and long-playing disc recording devices function effectively within the full audio spectrum extending from about 20 to 16,000 cycles per second and higher. Frequency modulation methods have widened the transmission band, and the full audio spectrum may now be transmitted and received without distortion.

Electrical amplifiers are now available having a substantially uniform response going much beyond the audio spectrum. Such amplifiers are capable of faithfully amplifying all of the partials and harmonics found in musical sounds. The frequency limitations of the older pickups have been overcome by modern electromagnetic pickups which yield a satisfactory response over the entire spectrum.

An audio network is composed of a chain of components, the first being the signal source which may take the form of a tape or record pickup, or a radio tuner. The second component is the amplifier responsive to the audio signal produced by the first component. The output of the amplifier is fed to a transducer or loudspeaker which converts the amplified signal to sound. It is this third component which is the primary concern of the present invention, for this component is currently the weakest link in the chain, and while it is possible to generate, transmit and amplify a signal faithfully, existing speakers tend to introduce frequency and spatial distortion and thereby defeat the advantages gained by high fidelity sound sources and amplification.

The significant qualities of a complete speaker system which includes an electrical source of known impedance, speaker units constituted by motors and diaphragms or cones, dividing networks, and acoustic loads, are its pressure-response, impedance, efficiency, directional and distortion characteristics.

No conventional loudspeaker appears capable of doing justice to the full audio spectrum, for the transducer characteristics called for in reproducing, say, the high-frequency range, are to some extent inconsistent with those requisite for the lower ranges. The problem of efficiently coupling a signal source to an acoustic load assumes a different form for different portions of the spectrum, and this problem cannot be satisfactorily solved by a single electromagnetic speaker.

While electrostatic speakers exhibit a good response in the upper ranges of the audio spectrum, they are highly inefficient in the lower ranges thereof and have a poor power handling capacity.

It has therefore been the practice in more elaborate installations to make use of multiple-speaker systems in which the individual speakers are adapted to cover complementary frequency ranges. Thus a woofer unit is used for the low or bass frequency range, a tweeter speaker for the treble range, and a mid-range speaker for the intermediate range. Among the advantages of dividing the audio spectrum in this manner are (*a*) improved frequency response and higher efficiency in that each unit covers a limited range, (*b*) improved transient response, since some expedients used to obtain extended range in a single speaker impair the transient response, (*c*) reduced intermodulation effects in that large amplitudes are confined to the low-frequency reproducer, and (*d*) reduced frequency modulation, this occurring when a single diaphragm moves with large amplitudes at low frequency while at the same time radiating high freqeuncies.

Multiple-speaker systems of known design have brought about significant improvements in sound reproduction. Nevertheless they still have certain imperfections which give rise to distortion and stand in the way of fully realizing the advantages to be gained from modern high fidelity equipment. For example, a two or three-speaker system requires the use of a cross-over network coupled to the speakers and acting to divide the applied signal and to route the frequencies thereof so that only the assigned portion of the spectrum reaches a particular speaker.

The reactance and capacitance characteristics of these networks are such as to deliver to each speaker an output which diminishes for frequencies outside of its assigned range. However, with a highly sensitive and efficient tweeter speaker, a response will be given even for highly attenuated low-frequency components in the signal, and this response is usually severely distorted, since the speaker output is substantially only within the treble range.

Another drawback encountered with conventional loudspeakers, particularly tweeters, is directionality. The higher the frequency of the sound, the more pronounced are its directional characteristics. Thus, while the low-frequency sounds will be distributed by a multiple system throughout the room, conventional tweeters tend to beam their output. Consequently the high-frequency components are overly intense in one area in the room and attenuated in another, relative to the other frequencies in the spectrum, thereby disturbing the spatial balance of the radiated sound.

A loudspeaker includes a relatively stiff cone supported within a frame by an elastic annulus or surround. The stiff cone moves with a piston-like motion, and the annulus provides compliance. With conventional designs, spurious vibrations are produced at the periphery of the cone. This suspension non-linearity is due to a lack of adequate compliance in the annulus, with a resultant interaction between the stationary frame and moving cone. A conventional annulus behaves as a spring, and with usual designs, the annulus is linear for only a limited range of displacement. Moreover, ordinary cones are of the soft paper type, and have a poor high frequency response.

A further problem encountered in a multiple-speaker systems has to do with the speaker enclosures for the individual units. Such enclosures are necessary to prevent destructive interference between the front and back waves from the speaker diaphragm. Because of practical space limitations, attempts have been made to provide so-called co-axial and tri-axial speakers in a common enclosure. But such enclosures cannot be designed to meet the specific acoustical requirements of the three complementary ranges, and while the common enclosure may be suitable for the low range, it is not adapted to meet the needs of the other ranges. On the other hand, to provide separate enclosures results in an awkward and space-consuming arrangement not suitable for most homes. This drawback is aggravated in stereophonic installations where the number of speakers and enclosures therefor are doubled.

Thus while a multiple-speaker arrangement is superior to a single-speaker arrangement, the defects mentioned above introduce distortions and spatial imbalances, and however fine the other components in the audio system, the listener is not offered natural and agreeable sound but only what commonly passes for high-fidelity sound which is characterized by piercing and directional high tones, coarse-grained mid-frequencies, and a booming, excessively resonant bass.

Accordingly, it is the main object of this invention to provide an integrated, multiple-speaker system which creates a natural sound and which combines in a single unit three separately enclosed speakers, each speaker smoothly covering a complementary range within the full audio spectrum without cross interference therebetween.

It is a further object of the invention to provide an integrated multiple-speaker system of the above type having a substantially uniform response throughout the complementary ranges, and with a balanced, non-directional distribution of sound.

Still another object of the invention is to provide enclosures for three speakers operating in complementary ranges, wherein all of the speakers are housed in a single, compact box containing separate enclosures for each speaker without interference therebetween, each enclosure affording an optimal acoustic environment for its associated transducer. A significant feature of the invention resides in an acoustic labyrinth forming an extended transmission line within a limited area.

Also an object of the invention is to provide a tweeter speaker which is substantially unresponsive to low-frequency components in an applied signal and which is uniformly responsive to high-frequency components, the radiated sound being non-directional to avoid beaming effects.

Yet another object of the invention is to provide a mid-range speaker of high compliance in the annulus and of exceptional stiffness in the radiating area, thereby avoiding break-up, poor transient response and other defects leading to distortion.

For a better understanding of the invention as well as other objects and further features thereof, reference is made to the following detailed description to be read in conjunction with the accompanying drawings, wherein:

FIG. 1 is a schematic diagram showing a multiple-speaker system in accordance with the invention and illustrating in section, specific details of the speaker design;

FIG. 2 is a front view of the tweeter speaker;

FIG. 3 is a front view of the mid-range speaker;

FIG. 4 is a perspective view of the multiple-speaker cabinet; and

FIG. 5 is a sectional view through the cabinet showing the various enclosures therein.

The Audio System

Referring now to the drawings, and more particularly to FIG. 1, an audio system in accordance with the invention is illustrated, the system comprising a signal source **10** whose output is applied through an amplifier **11** of any standard design to a multiple-speaker arrangement constituted by a tweeter speaker **12**, a mid-range speaker **13**, and a woofer **14**. The audio signal source **10** may in practice take the form of a record cartridge or tape pickup, a microphone, a radio tuner, or any other source of audio signals. It is assumed that the quality of the audio source is of a high order and hence the function of the amplifier and of the speaker system is to amplify and reproduce the signals without distortion. In the case of stereophonic systems, a pair of audio chains of the above type must be provided.

The output of the amplifier is fed through a cross-over network **15** of any known design to the three speakers in a manner whereby the audio spectrum is divided so as to apply the treble range to the tweeter **12**, the bass range to the woofer **14**, and the intermediate range to the mid-range speaker **13**. The cross-over network may be of any known filter design, and must be such as to introduce attenuation, such as 12 db per octave, as the frequency departs from the dividing line.

Preferably the cross-over network takes the form of a single reactive element to reduce the passage of highs

to the woofer, a single non-polarized capacitive element to reduce the passage of bass tones to the mid-range speaker in conjunction with a single reactive element to cut down the entry of highs to the mid-range and a single capacitive element to reduce the passage of bass tones to the tweeter. The present invention makes it possible to use dividing networks having a gradual rather than an abrupt cut off at the dividing lines, for the latter characteristic introduces distortion.

In order to obtain effective reproduction of the applied signal, the multiple-speaker system must provide a smooth response versus frequency characteristic, good spatial distribution of the radiated sound, and low transient distortion. And while the woofer by its very nature is unresponsive to any high-frequency components in the signal applied thereto, it is important that the tweeter be substantially insensitive to low-frequency components which are delivered in attenuated form by the cross-over network, for otherwise these components will be produced with severe distortion.

The Speaker Units

We shall therefore first address ourselves to the design of the tweeter **12**. Tweeter **12** is of electromagnetic design and includes the usual motor in the form of a coil **16** wound on a tube **17** and movable in the air gap of a permanent magnet core **18**. A dome-shaped paper or plastic diaphragm **19** of relatively rigid material is attached to the end of tube **17**. The tube and the dome are supported and centered by means of a pliable membrane **20**. Assuming good design and paper stiffening, the tweeter will have a linear response in the treble range.

However, there are two factors which introduce spatial and frequency distortion. First, the conventional speaker in the treble range tends to beam the radiated sound, thereby creating a spatial imbalance; and second, it will respond in non-linear fashion to low-frequency tones passing through the cross-over network. To avoid these drawbacks, there is attached centrally to the dome a truncated filled cone, generally designated by the numeral **21**. The filled cone projects axially from the dome, the smaller or apex end thereof being attached thereto, as by epoxy cement. The filled cone itself is constituted by a skin **22** of aluminum or magnesium foil, filled with a light and rigid plastic **22*a***, preferably an epoxy foam.

Thus the dome **19** primarily acts to drive the filled cone **21**, which by reason of its flat base and tapered wall, tends to radiate omnidirectionally, thereby effectively diffusing what would otherwise be a beam of sound. Since the filled cone is bonded at its small end or apex to the dome, this constricted coupling is highly inefficient or mismatched with respect only to the low-frequency components, the coupling being efficient in the treble range. Thus while the dome responds somewhat to the low-frequency components, these tones are not radiated.

In the mid-range speaker **13**, a conical diaphragm **24** centrally attached to the voice coil **22**, which is movable within the air gap of a permanent magnet **23** in the usual manner. The periphery of the cone **24** is attached by an annulus **25** to the circular mounting frame or basket **26** of the speaker. Hard, impregnated or calendered papers are ordinarily used for cones when loudness efficiency and high-frequency response are important. The transient response of diaphragms of this type is necessarily poor, since non-center moving modes are not effectively damped.

Accordingly, it is the practice in mid-range speakers to make use of soft or felted blotter-like cones when some loss in high-frequency response can be tolerated and a smoother response curve with reduced transient distortion is required. The loudness efficiency of high-loss cones of this type is several decibels lower than that of low-loss cones.

In accordance with the present invention, the cone **24** is of soft, high-loss material to improve transient response, but is supplemented by a relatively stiff and light central radiator area **27** which enhances the high-frequency response. In practice, this area **27** is formed by applying a stiffening agent, such as epoxy, to the region surrounding the apex of the otherwise soft paper cone.

In order to provide greater freedom of excursion without appreciably affecting the stability of the voice coil, and to impart better damping qualities to the cone suspension, the annulus is preferably formed of a ring of porous and flexible polyurethane foam or similar material, such as vinyl foam, which is inherently compliant and because of its cellular structure, substantially non-resilient, so that after deformation it slowly returns to its initial configuration. The cross-sectional configuration of the annulus is arcuate to increase the compliance. Thus the annulus does not act as a spring to impart motion to the cone nor will it transmit reflections from the supporting basket or frame.

The low-frequency woofer **14**, in accordance with usual practice, should have the largest possible cone area to provide effective coupling at the bass frequencies to the acoustic load, and may also be provided with a highly compliant annulus for the reasons set out above.

The Speaker Enclosures

Referring now to FIGS. 4 and 5, the box for enclosing the three speakers is shown, and it will be seen that the box includes a front baffle **28** having three openings therein about which the three speakers are mounted, the woofer **14** being mounted adjacent the lower end of the baffle, the mid-range speaker **13** at about the center, and the tweeter **12** near the upper end. In practice more than one tweeter may be used. Also multiple mid-range speakers may be employed.

The box further includes a back panel **29**, a top panel **30**, side panels **31** and **32**, and a base board **33**. The various elements of the box may be made of any desired material such as plywood, pressed cellulose board or laminated plastic, with an approximate panel thickness of ¾ of an inch or more. The construction must be highly rigid with the joints between meeting panels effectively airtight.

The treble and mid-range speakers must be mounted on the baffle so as to fully expose their cones and provide proper edge radiation. Preferably the filled cone on the tweeter should project somewhat beyond the plane of the baffle to avoid muffling thereof.

The box is divided by a vertical centerboard **34** into two sections A and B of equal geometry. The centerboard does not connect with the base of the box but with a horizontal deck plate **34***a*, which is raised above the base and which joins the baffle board **28** to define a narrow slot opening **35** below the baffle.

As is known, the phase and amplitude of the backside radiation of a cone may be altered by coupling an acoustic transmission line thereto. To conserve space, this line in the present invention is folded to form a labyrinth, and is made highly dissipative by lining the walls thereof with fibrous material **36** such as mineral wool or glass, paper or textile fibres.

Phase shift between the diaphragm and the slot opening is due to the time of transmission in the line, and the effective length of the line is effectively extended by means of an acoustic resistance unit **37** in the upper end of the centerboard. This unit, which may be Armstrong "Reselopac" medium grade, or other resistive material having circuitous sound paths between opposing faces thereof, serves to increase the transmission time of the wave which is propagated from the back of the woofer cone successively up section A, as indicated by the arrows, through the resistance unit, down section B, and then out through the front slot **35**.

At very low frequencies, the line is a small fraction of a wavelength long, and as the phase shift is negligible, the slot and diaphragm are out of phase. When, however, the line is one-quarter of a wave length long, it acts as an impedance inverter, and the cone sees a high impedance so that radiation from the slot opening is at a maximum. Hence non-linear distortion is reduced at or near this frequency and the resonant frequency of the diaphram may be placed thereat to aid damping. Between this frequency and the one for which the line is half a wave length long, the slot phase shifts progressively but maintains some component of its radiation in phase which the diaphragm outside the line. Because of the infinite series of resonant and anti-resonant frequencies of the line, high absorption material **36** is introduced to prevent objectionable resonances and radiated out-of-phase components of the slot, and most of the rear-side radiation is absorbed.

Preferably in accordance with the invention, a predetermined relationship is established between the cross-sectional area of the woofer, the labyrinth and the slot opening. Assigning the value X to the cross-sectional area of the woofer, the cross-sectional area of the labyrinth should be at least twice X, whereas that of the slot opening, one-quarter X. Thus the labyrinth acts neither as a horn, a resonant pipe nor a Helmholz resonator but is derivative in some respects from each of these acoustic elements and serves to couple the back loading of the woofer cone to its front loading throughout the base range but without peaking or resonant effects which would stress selected frequencies and thereby result in boominess.

The mid-range speaker is provided with a total enclosure **38**, and the tweeter with a total enclosure **39**. Both of these enclosures are preferably made of Novaply, a very dense and heavy pressed wood. These total enclosures prevent radiation from the back side of the respective diaphragms and thereby avoid destructive interference between the front and back wave thereof. While these total enclosures for the tweeter and mid-range speakers lie within section A of the acoustic labyrinth, they do not appreciably interfere with the back transmission from the woofer speaker. At the same time they prevent cross-interference between the three speakers within the acoustic labyrinth.

Thus a highly compact, efficient and smoothly responsive sepaker system is provided, all within a single box which may also contain the cross-over network as well as suitable adjustable attenuator resistors for the respective speaker units for balancing their relative outputs.

While there has been disclosed what are considered to be preferred embodiments of the invention, it will be manifest that many changes and modifications may be made therein without departing from the essential spirit of the invention. It is intended, therefore, in the annexed claims to cover all such changes and modifications as fall within the true scope of the invention.

What is claimed is:

1. A multiple loudspeaker system comprising a box having a front baffle and a base, a woofer speaker mounted on said baffle about a port adjacent the lower end thereof, a tweeter speaker mounted on said baffle about a port adjacent the upper end thereof, said speakers radiating forwardly through said ports, a vertical centerboard dividing said box into front and rear sections, a horizontal deck displaced above said base and supported between the lower edge of said baffle and the lower edge of said centerboard to define a slot communicating between said rear section and he front of said box, an acoustic resistance unit forming the upper portion of said centerboard whereby sound emanating from the rear of said woofer speaker travels in a transmission path along the front section of said box and through said resistance unit into the rear section thereof, the sound then being propagated downwardly through said rear section and outwardly through said slot.

2. A system as set forth in claim 1, wherein said tweeter is housed within said front section in a total enclosure attached to the rear of said baffle.

3. A system as set forth in claim 1, further including a mid-range speaker mounted about a port intermediate the woofer and tweeter speakers on said baffle, and a total enclosure for said mid-range speaker attached to the rear of said baffle.

4. A multiple loudspeaker system comprising an enclosure box having a front baffle and a base, a woofer speaker mounted on said baffle about a port adjacent the lower end thereof, a tweeter speaker mounted on said baffle about a port adjacent the upper end thereof, a mid-range speaker mounted on said baffle about a port intermediate the other ports, said speakers radiating forwardly through said ports, a vertical centerboard dividing said box into front and rear sections, separate total enclosures for said tweeter and mid-range speakers within said front section, a horizontal deck displaced above said base and supported between the lower edge of said baffle and the lower edge of said centerboard to define a slot, an acoustic resistance unit forming the upper portion of said centerboard whereby sound emanating from the rear of said woofer speaker travels in a transmission path upwardly in the front section of said box and through said resistance unit into the rear section thereof, the sound then being propagated downwardly through said rear section and outwardly through said slot.

5. A system as set forth in claim 4, wherein said transmission path is lined with acoustically absorbent material.

6. A system as set forth in claim 4, wherein the front and rear sections having substantially the same cross-sectional dimension, which dimension is at least twice that of said woofer speaker, the cross-sectional dimension of the slot being one-quarter of the woofer speaker.

7. In an audio network provided with an audio amplifier and a cross-over network coupled to the output thereof to divide the low-frequency from the high-frequency components, a multiple loudspeaker system comprising an enclosed box having a front baffle and a base, a woofer speaker mounted on said baffle about a port adjacent the lower end thereof, a tweeter speaker mounted on said baffle about a port adjacent the upper end thereof, said speakers being coupled to said network whereby the high-frequency components are routed to the tweeter and the low-frequency components to the woofer, said speakers

radiating forwardly through said ports, a vertical centerboard dividing said box into two like sections, a horizontal deck displaced above said base and supported between the lower edge of said baffle and the lower edge of said centerboard to define a slot, an acoustic resistance unit forming the upper portion of said centerboard whereby sound produced at the rear of said woofer speaker travels in a transmission path upwardly in the front section of said box and through said resistance unit into the rear section thereof, the sound then being propagated downwardly through said rear section and outwardly through said slot.

8. A multiple loudspeaker system comprising an enclosed box having a front baffle and a base, a woofer speaker mounted on said baffle about a port adjacent the lower end thereof, said woofer speaker having a predetermined cross-sectional dimension, a tweeter speaker mounted on said baffle about a port adjacent the upper end thereof, said speakers radiating forwardly through said ports, a vertical centerboard dividing said box into two sections of like cross-sectional dimension which is at least twice that of said woofer speaker, a horizontal deck displaced above said base and supported between the lower edge of said baffle and the lower edge of said centerboard to define a slot whose cross-sectional dimension is about one-quarter of said woofer speaker, an acoustic resistance unit forming the upper portion of said centerboard whereby sound produced at the rear of said woofer speaker travels in a transmission path upwardly in the front section of said box and through said resistance unit into the rear section thereof, the sound then being propagated downwardly through said rear section and outwardly through said slot.

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