

[54] **DEVICE TO EFFECTIVELY ELIMINATE THE MOTION INDUCED BACK EMF IN A LOUDSPEAKER SYSTEM IN THE REGION OF FUNDAMENTAL ACOUSTIC RESONANCE**

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[22] Filed: **June 14, 1973**

[21] Appl. No.: **370,046**

Related U.S. Application Data

[63] Continuation of Ser. No. 228,547, Feb. 23, 1972, abandoned.

[52] U.S. Cl. **179/1 A, 179/1 D, 179/115.5 R, 179/115.5 DV**

[51] Int. Cl. **H04r 9/00**

[58] Field of Search ... **179/1 A, 1 D, 1 FS, 115.5 R, 179/115.5 DV**

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[57] **ABSTRACT**

A loudspeaker system is provided wherein a circuit, including a second voice coil and a series LC resonant circuit, is connected in parallel with the conventional voice coil. The impedance of the second voice coil is lower than that of the conventional coil and the resonant circuit is designed to resonate at the fundamental acoustical resonant frequency of the speaker cone so that a low impedance path for audio amplifier drive current is provided in the region of resonance. The second coil is ineffective at frequencies off resonance and by proper choice of the impedance of this coil, the speaker response at resonance can be matched to that off resonance. A parallel LC resonant circuit connected in series with the conventional coil is designed to effectively remove this coil at resonance and hence eliminate the effect of the back e.m.f. generated thereby.

11 Claims, 6 Drawing Figures

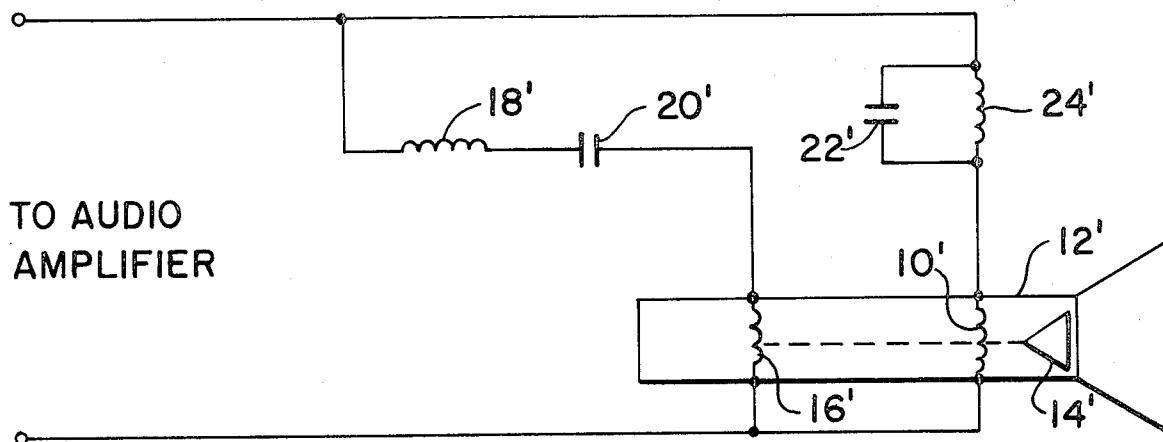


FIG. 1

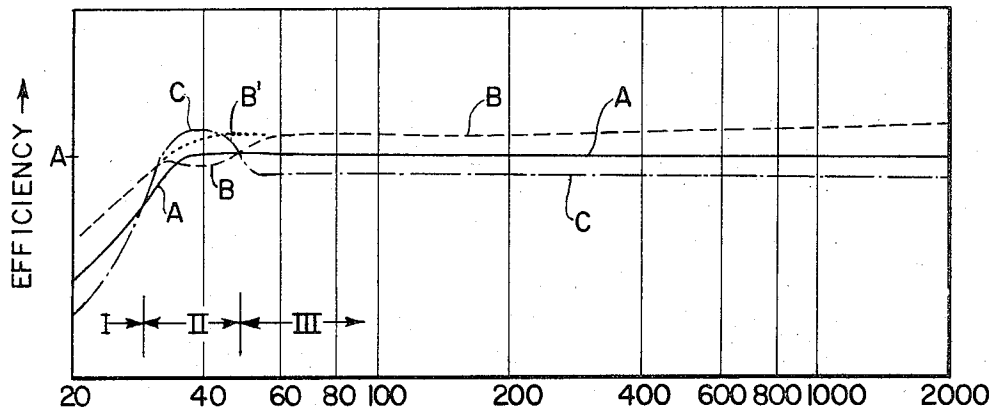


FIG. 5

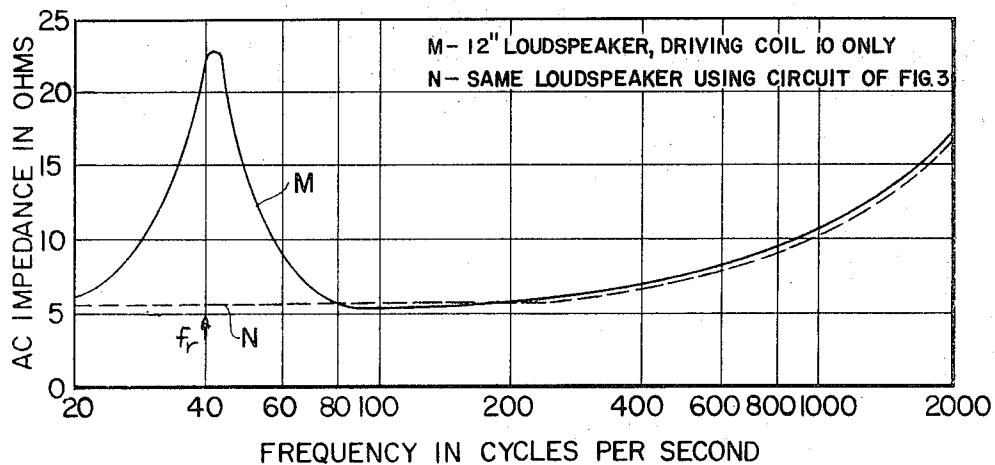


FIG. 6

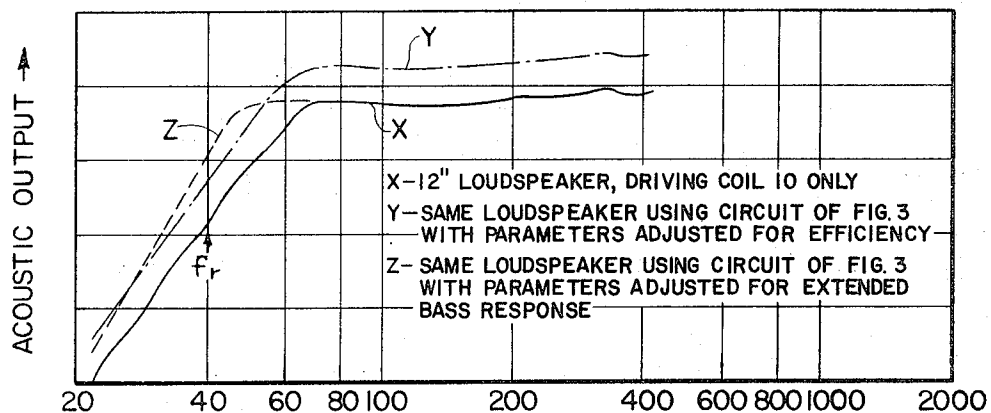


FIG. 2

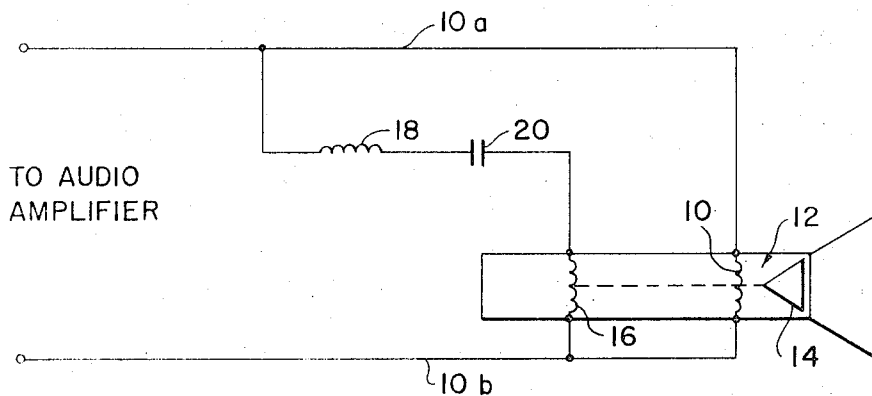


FIG. 3

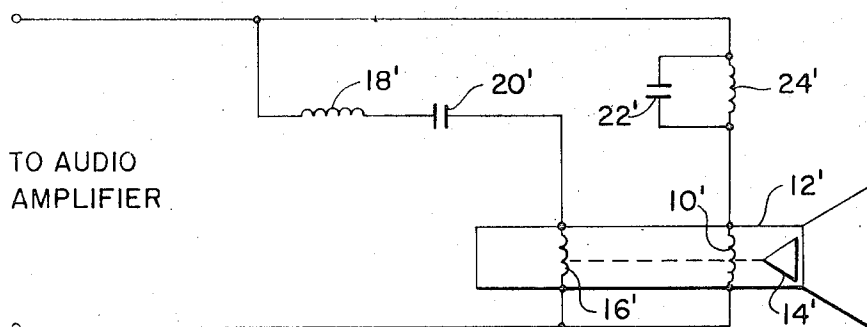
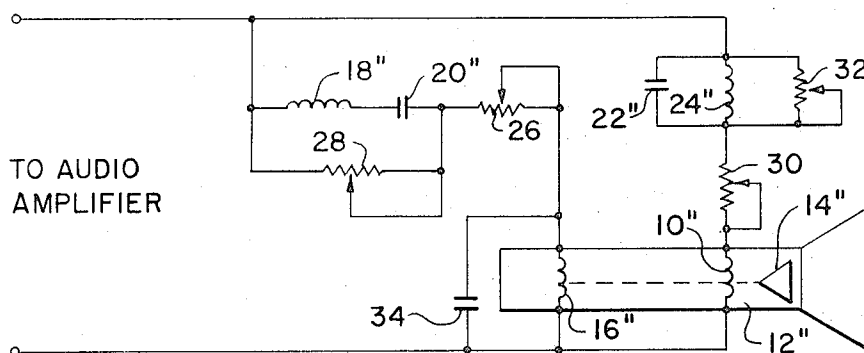


FIG. 4



A DEVICE TO EFFECTIVELY ELIMINATE THE MOTION INDUCED BACK EMF IN A LOUDSPEAKER SYSTEM IN THE REGION OF FUNDAMENTAL ACOUSTIC RESONANCE

This is a continuation, of application Ser. No. 5 228,547 filed 2/23/72, now abandoned.

FIELD OF THE INVENTION

The present invention relates to loudspeaker devices and more particularly to a loudspeaker system which provides increased efficiency without sacrificing bass response and which enables control of the speaker impedance and acoustic output in the region of the fundamental resonant frequency of the acoustical cone.

BACKGROUND OF THE INVENTION

Generally speaking, given a conventional acoustic suspension loudspeaker system which has been adjusted to provide a flat response and which utilizes an enclosure of a given size the efficiency of the system can be increased only by raising the resonant frequency of the system. Such an approach decreases the bass response of the system and hence is undesirable from at least this standpoint.

Although it might be supposed that an efficiency increase could be obtained with an increase in magnetic flux density in the voice coil gap, such is not the case or, more accurately, this is not the whole story. Specifically, conventional loudspeakers suffer the disadvantage that when the magnetic flux density in the gap of the voice coil is increased, the efficiency of the speaker, while increasing in the regions above and below the fundamental acoustic resonant frequency, actually decreases in the region of resonance. Further, this is particularly true of sealed enclosure and acoustic suspension-type loudspeakers. The problem results from the fact that at the resonant frequency of the loudspeaker, which is a mechanical-acoustic resonance, the cone-coil mass and the elasticity of the air cancel and because the resistance of the suspensions is negligible, the "motor," i.e., the voice coil and magnetic field driving forces, provides principle control of the cone excursion and hence the acoustic output of the speaker. Because the cone excursion and velocity tend to increase at resonance, the loudspeaker motor tends to act as a generator and attempts to return current to the amplifier. More particularly, the motor generates a voltage, generally referred to as a back e.m.f., which is out of phase with and in opposition to the drive voltage from the amplifier and, hence, produces an increase in the terminal impedance of the loudspeaker and gives rise to an opposing current flow in the voice coil. The back e.m.f. generated will be larger with a larger magnet, i.e., with a higher flux density, and hence the use of a larger magnet results in a higher terminal impedance. Because conventional audio amplifiers are negative feedback devices and hence deliver an essentially constant voltage, an increase in the terminal impedance of the loudspeaker will cause a reduction in current flow in the voice coil at resonance. Thus, the disadvantageous situation mentioned above obtains, that is, a larger magnet, i.e., an increase in flux density, produces an increase in efficiency above and below resonance but produces a decrease in efficiency at resonance and an uneven overall frequency response results. Conversely, a decrease in flux density produces an increase in efficiency at resonance and a decrease

in efficiency off resonance and, again, an uneven frequency response.

From the foregoing, it will be appreciated that prior to the present invention the overall efficiency of a loudspeaker system such as discussed hereinabove could only be improved by raising the resonant frequency of the system and hence at the cost of decreased bass response.

SUMMARY OF THE INVENTION

In accordance with the present invention, a loudspeaker system is provided wherein efficiency may be increased without sacrificing bass response. More particularly, a loudspeaker is provided which permits control of the terminal impedance in the region of resonance, and thereby enables the use of higher flux densities without the cost of decreased efficiency at resonance. The invention permits the efficiency at resonance to be matched to that above and below resonance so that a smooth overall frequency response can be obtained with larger magnet.

According to a presently preferred embodiment of the invention, a loudspeaker is provided with a second voice coil, in addition to the conventional voice coil, which second coil has a lower impedance than the conventional coil and which is connected in series with a tuned circuit designed to resonate at the acoustical resonant frequency of speaker. The circuit including the coil is connected in parallel with the conventional coil and presents a lower impedance path to the audio amplifier in region of resonance so that the drive current from the amplifier is increased. The second coil is ineffective at frequencies off resonance and, hence, by suitably adjusting the impedance of the coil, the current flow at resonance can be controlled separately from the current flow above and below resonance, and the acoustic output of the speaker at resonance can be correspondingly controlled to match the off resonance response. The second voice coil may be wound over or under the conventional coil and the impedance thereof controlled by using fewer turns and/or larger wire. The tuned circuit can simply comprise series-connected capacitor and inductor devices. A parallel tuned circuit connected in series with the conventional coil and designed to resonate at the resonant frequency of the speaker improves the efficiency of the system by effectively removing the coil at resonance and hence eliminating the effect of the back e.m.f. generated thereby. Variable resistors may be added to control the Q of the tuned circuits and the effects of the capacitance and inductance in the system.

It should be understood that the dividends provided by the invention can be taken in ways other than in increased efficiency. For example, the bass response of the speaker can be extended by adding more mass to the cone so as to lower the resonant frequency thereof and still produce a smooth response across the entire frequency band. Further, after the mass is added, the volume of loudspeaker enclosure can be reduced so as to raise the response back to the previous level. This approach provides the same response as before while permitting use of an enclosure which is smaller than conventional.

Other features and advantages of the invention will be set forth in or apparent from the detailed description of the preferred embodiments found hereinbelow.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is curve plotting efficiency versus frequency used in explanation of the disadvantages of conventional loudspeakers;

FIG. 2 is a schematic circuit diagram of a loudspeaker system in accordance with a first embodiment of the invention;

FIGS. 3 and 4 are schematic circuit diagrams of two further embodiments of the invention; and

FIGS. 5 and 6 are curves used in explanation of the operation of the loudspeaker system of the invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

As discussed hereinabove, in accordance with conventional design techniques, in a properly designed acoustic suspension system wherein the voice coil-magnetic field strength has been adjusted to provide a flat response and a conventional 2 cubic foot or so enclosure is utilized, efficiency can be increased only by raising the resonant frequency of the system. For a conventional design, using a given size woofer or bass speaker operating into the mid range (such as an 8, 10 or 12 inch diameter unit) which provides a "Q" of one, i.e., a flat response from the resonant frequency, f_r , up through the remainder of the range, (as discussed by Kloss in an article entitled "Hoffman's Iron Law" appearing in the Mar. 1971 issue of Audio, at pages 30 to 32 and 56), the efficiency, E , above approximately 150 Hz, is given by the relationship $E = f_r^3 \times \text{enclosure volume}$, where f_r , as stated above, is the fundamental cone resonant frequency. This relationship implies that, in a conventional design, in order to raise efficiency and still maintain a flat response it is necessary to raise the resonant frequency or increase the volume of the enclosure. Any attempt to increase efficiency in conventional speakers by increasing the flux density in the voice coil gap suffers the disadvantages discussed above and illustrated in FIG. 1. Specifically, curve A shows frequency response of a conventional acoustic suspension loudspeaker wherein the motor, i.e., voice coil and magnetic flux, is adjusted to provide a flat response. The resonant frequency is labeled f_r in FIG. 1 and the frequency range is divided into three regions, viz., a first region, denoted I, below resonance, a second region, denoted II, adjacent resonance and a third region, denoted III, above resonance. Curve B, shown in dashed lines, represents the frequency response of the speaker when the magnetic strength of the motor is increased. As illustrated, the efficiency is increased in regions I and III and decreased in region II. Curve C, shown in chain lines, represents the response with the magnetic field strength of the motor decreased and illustrates that a decrease in efficiency results in regions I and III and an increase results in region II. Thus the curves of FIG. 1 confirm what was said hereinabove regarding the effect of an increase in flux density in the voice coil gap. The dotted line portion of curve B illustrates the effect produced by the present invention, i.e., the elimination of the "dip" in the response in region of resonance and a resultant smooth response at increased efficiency. FIGS. 2 to 4 illustrate circuits incorporating the invention and will be discussed now.

Referring to FIG. 2, a first embodiment of a loudspeaker system in accordance with the invention is

shown. The system includes a first voice coil 10 adapted through means of conductors 10a and 10b to be connected to the audio amplifier of the speaker as indicated. This portion of the system represents a conventional voice coil circuit for a loudspeaker and coil 10 can, for example, be a conventional woofer. The voice coil 10 is part of a speaker unit indicated at 12 and drives a cone 14.

In accordance with the present invention, a second, relatively low impedance coil, denoted 16, is also utilized. Coil 16 is preferably wound over or under coil 10 in parallel therewith and the number of turns coil 16 and/or the gauge wire used therein are chosen such that the impedance of coil 16 is less than that of coil 10, and hence the drive current from the audio amplifier through coil 16 is greater than that through coil 10. Coil 16 is connected in series with a resonant circuit formed by an inductor 18 and a capacitor 20. The values of inductor 18 and capacitor 20 are chosen such that the series tuned circuit formed thereby resonates at the fundamental acoustical resonant frequency of the cone 14. Thus the circuit including coil 16, inductor 18 and capacitor 20 presents a very low impedance at this resonant frequency, this impedance increasing at frequencies off resonance so that coil 10 is effective at these frequencies. The impedance of coil 16 can be adjusted to, within practical limits, any desired value and hence the current flow in the region of resonance can be controlled separately from the current flow for frequencies above and below resonance. Correspondingly, the acoustic output of the speaker at resonance can be increased at resonance to match that above and below resonance.

As the impedance of coil 16 is lowered, by using fewer turns, parallel turns or larger wire, the current through coil 10 decreases and can even go negative. I have found that a capture ratio occurs as the impedance of coil 16 is lowered, while still maintaining a value of no lower than approximately 5 ohms, such that the current in coil 10 becomes negative and coil 10 acts as a generator rather than a motor, the back e.m.f. generated by coil 10 which is in phase opposition to the amplifier voltage being greater than the amplifier voltage across the coil. Thus disconnecting coil 10 from the circuit at the resonant frequency will allow still more current to flow and this fact is taken advantage of in the embodiment of FIG. 3.

Referring to FIG. 3, a second embodiment of the invention is shown which is similar to that of FIG. 2 and in which corresponding elements have been given the same numbers with primes attached. In the embodiment of FIG. 3, a parallel LC circuit formed by capacitor 22 and inductor 24 is added in series with voice coil 10. The parallel LC circuit is designed to present a high impedance to voice coil 10 at the resonant frequency of the speaker and hence effectively remove coil 10 from the circuit at resonance. Such an approach provides even greater control over the total current flow and enables the acoustic output to be increased over that provided by the circuit of FIG. 2.

Referring to FIG. 4, a third embodiment of the invention is shown which is similar to that of FIGS. 2 and 3 and in which corresponding elements have been given the same numbers with double primes attached. A first variable resistor 26 is connected in series with inductor 18' and capacitor 20' and a second variable resistor 28 is connected in shunt across these elements, re-

sistors 26 and 28 enabling control of the Q of, and the amount of effect of, the LC circuit formed by elements 18'' and 20''. Further resistors 30 and 32 serve the same purpose regarding the parallel tuned circuit formed by capacitor 22'' and inductor 24''. In addition, a capacitor 34 is connected in parallel across voice coil 16 the value of which is chosen to present a high impedance across coil 16 at resonance and a low impedance above resonance. Capacitor 34 hence acts as a load for the back e.m.f. generated by coil 16 thus damping this back e.m.f. and improving the transient response of the system.

The Q of the LC circuits in FIGS. 2 to 4 may be spread or sharpened by adjustment of the values of the inductors and capacitors to match the rise of the fundamental resonant frequency of the acoustical cone. Referring to FIG. 5, the solid curve M shows the impedance characteristic for a conventional 12-inch sealed box loudspeaker using a single coil as discussed above and, as illustrated, shows an increase in impedance up to 20 ohms. The dashed curve N represents the impedance characteristic of the same loudspeaker modified in accordance with the invention and with the values of the inductors and capacitors adjusted to provide optimum response as just discussed. Curve N shows an impedance variation of less than one ohm from 300 Hz through resonance down to 20 Hz.

Referring to FIG. 6, the solid curve X shows the acoustic output characteristic of a conventional 12-inch loudspeaker whereas dashed-line curve Y shows the same loudspeaker modified in accordance with the invention and adjusted to provide increased efficiency. Curve Y generally corresponds in shape to curve B-B' of FIG. 3 and illustrates how the invention enables the acoustical output to be brought up in the region of resonance so as to match the increase above and below resonance. The chain-line curve Z shows the bass extension possible using the circuit of FIG. 2 with the parameters adjusted to provide optimum response. Curve Z illustrates what was said above regarding taking the dividends provided by the invention in other than increased efficiency. By adding more mass to lower the resonant frequency of the cone and taking the acoustical response down to normal above resonance, the bass response may be extended as shown. Further, after adding mass, the volume of the loudspeaker enclosure may be lowered to again raise the resonant frequency so that the original response is produced with a smaller enclosure.

In addition to the advantages discussed above, the loudspeaker of the invention also produces lower harmonic distortion, better transient response at resonance due to lower impedance and better damping, less phase shift due to the more resistive load presented to the amplifier and better impedance matching to the standard 8-ohm impedance of modern transistor amplifiers. Further, no additional amplifier power is required, as compared with conventional designs.

The invention can, of course, be applied to more than a single loudspeaker, to speakers having more than one voice coil, and to other than sealed enclosure devices.

While the invention has been described with reference to presently preferred, exemplary embodiments

thereof, it will be understood by those skilled in the art that variations and modifications can be effected in these exemplary embodiments without departing from the scope and spirit of the invention.

I claim:

1. In a loudspeaker system including at least one speaker unit comprising at least one voice coil adapted to be connected to an audio amplifier and an acoustical cone driven by the voice coil, the improvement comprising an electrical circuit connected in parallel with the at least one voice coil comprising a further voice coil having a lower impedance than the at least one voice coil and a resonant circuit, connected in series with said further voice coil, which resonates at the fundamental acoustical resonant frequency of the cone so as to present a low impedance path to the amplifier in the region of resonance such that current flow through the further voice coil is increased in said region and to effectively eliminate the motion induced back emf in the loudspeaker system in the region of fundamental resonance, said further voice coil being ineffective at frequencies outside of said region.

2. A loudspeaker system as claimed in claim 1 wherein said resonant circuit comprises a capacitor and an inductor connected in series so as to present a low impedance path in said region and a high impedance path both above and below said region.

3. A loudspeaker system as claimed in claim 2 further comprising a further resonant circuit connected in series with the at least one voice coil for presenting a high impedance to the amplifier in the said region, said further resonant circuit presenting a lower impedance above and below said region.

4. A loudspeaker system as claimed in claim 3 wherein said further resonant circuit comprises a capacitor and inductor connected in parallel.

5. A loudspeaker system as claimed in claim 1 further comprising a capacitor connected in shunt with said further voice coil.

6. A loudspeaker system as claimed in claim 1 wherein said further coil is wound on top of the at least one coil.

7. A loudspeaker system as claimed in claim 1 wherein said further coil is wound beneath the at least one coil.

8. A loudspeaker system as claimed in claim 1 wherein the further coil has fewer turns than the at least one coil.

9. A loudspeaker system as claimed in claim 1 wherein the wire size of the wire in the further coil is greater than that of the at least one coil.

10. A loudspeaker system as claimed in claim 4 further comprising variable resistor means for controlling the "Q" of said resonant circuits.

11. A loudspeaker system as claimed in claim 10 wherein said variable resistor means comprises a first variable resistor connected in series with said series resonant circuit and a second variable resistor connected in parallel across said series resonant circuit and a third variable resistor connected in series with said parallel resonant circuit and a fourth variable resistor connected in parallel across said parallel resonant circuit.

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