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## [54] LOUDSPEAKER SYSTEM


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[51] **Int. Cl.** .....**H04r 3/12**

[58] **Field of Search**.....179/1 D, 1 DD, 1 DM, 1 VL, 179/1 E; 333/18 T



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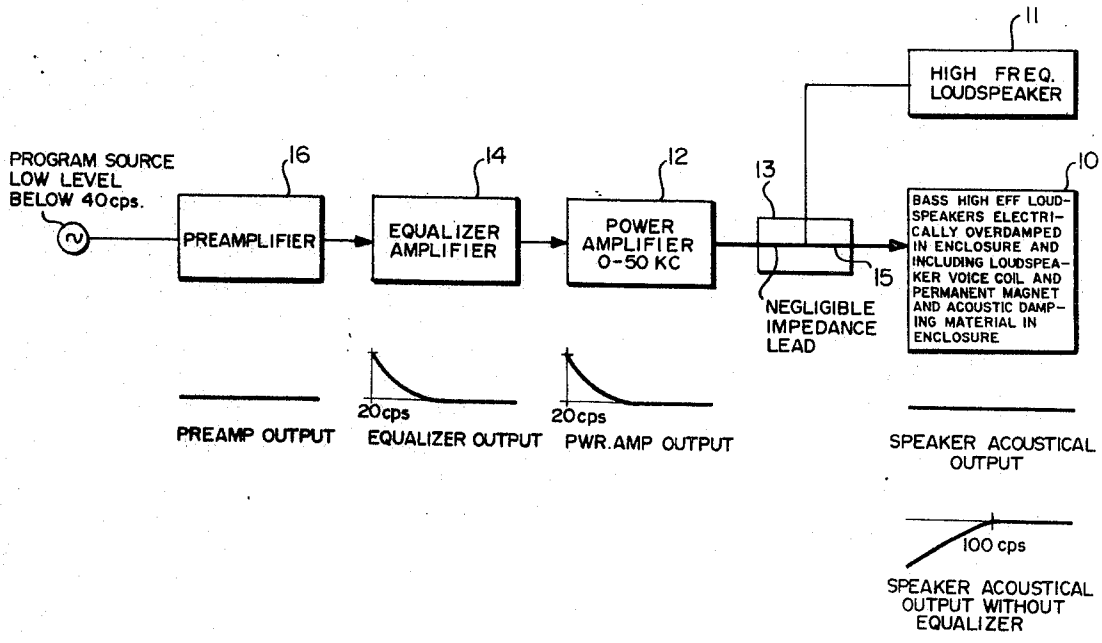
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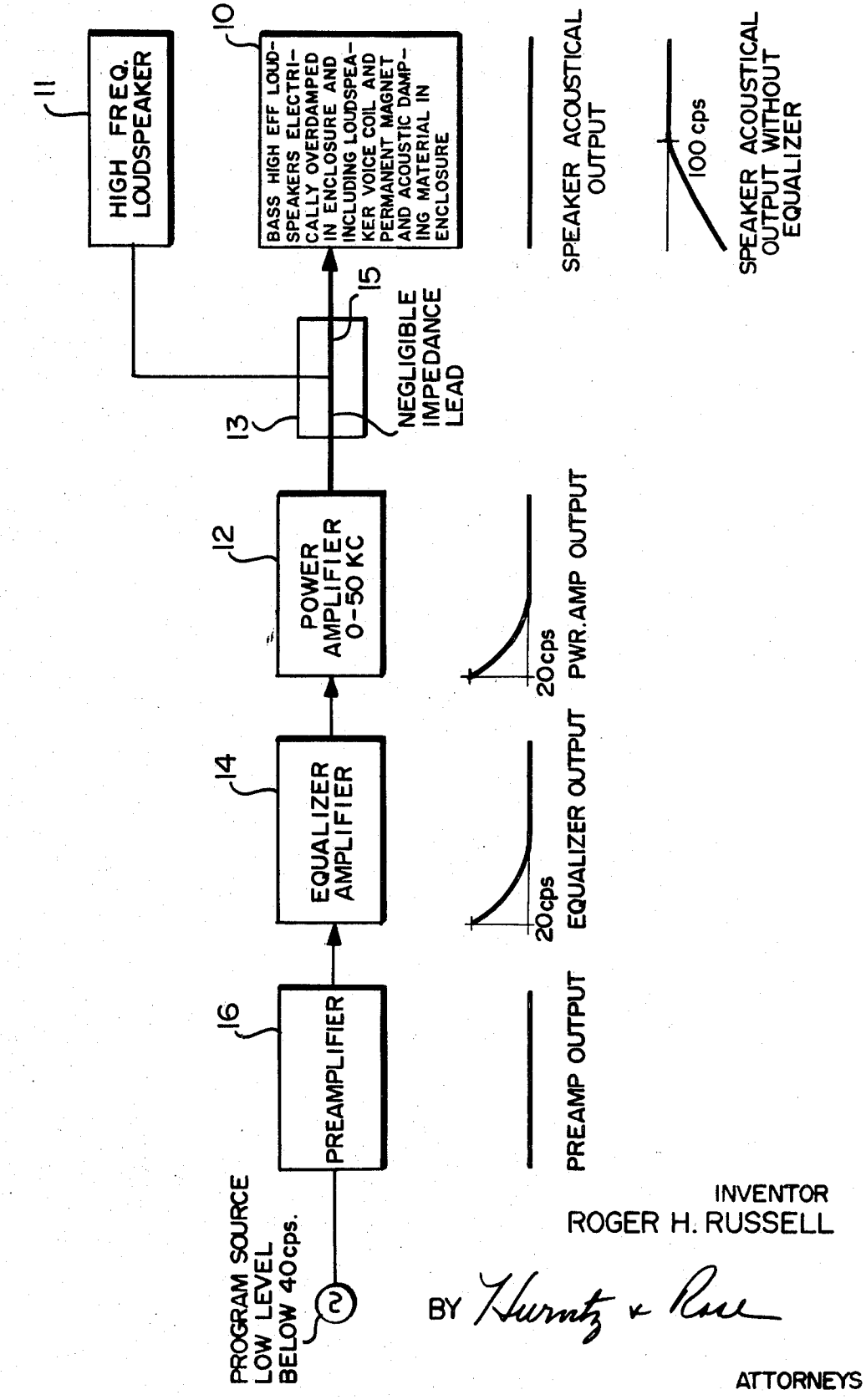


[57] **ABSTRACT**

A flat acoustic pressure response, compensating network, driver amplifier and loudspeaker system, the driver amplifier being an effective voltage source and the loudspeaker system containing multiple speakers including a low frequency loudspeaker mechanism which is both efficient and highly damped magnetically by providing a powerful magnetic flux field, and a many turn motor coil which is capable of enforcing wide cone excursions. The loudspeaker mechanism in the enclosure without acoustic damping has a higher Q than the same mechanism in the same enclosure with acoustic damping added. Response gradually rolls off below 150 Hz and down to system resonance approaching a rate of 6 dB per octave. Below system resonance rolloff gradually approaches 12 dB per octave. Rolloff prior to system resonance occurs due to a high flux density, long motor turns, low resistance, and low moving mass producing a Q at system resonance of 0.5 or less. The speaker is operated at high efficiency above 150 Hz and its rolloff is compensated to about 20 Hz by a compensation equalizer. This equalizer is connected to the input of the driving power amplifier and involves about 20 dB of boost at 20 Hz.


**2 Claims, 1 Drawing Figure**






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# LOUDSPEAKER SYSTEM

## BACKGROUND OF THE INVENTION

Present practice in achieving a flat acoustical response down to system resonance with direct radiator loudspeakers in small sealed enclosures is to adjust the parameters of Mass, Resistance, Flux density in the voice coil magnetic gap, and length of turns in the gap for optimum performance. A small sealed system referred to here is defined as a loudspeaker in a sealed enclosure having acoustical absorbing material inside, the stiffness of air in the enclosure being a major portion of the effective speaker suspension stiffness which in conjunction with effective moving mass of the loudspeaker, determines the system resonant frequency. Three conditions of these parameters in the vicinity of system resonances are indicative of low frequency performance; namely, underdamped, critically damped, and overdamped. In the underdamped case the mechanical Q is greater than 0.5 and the system tends to oscillate when the applied signal is removed. In addition, when the Q is greater than 1, response rises in the region of system resonance. When the Q equals 1, response is essentially flat down to system resonance. In the critically damped case Q is 0.5 and the system is just on the verge of oscillating when the signal is removed. The acoustic response, however, rolls off prior to system resonance. A Q of 0.5 is normally optimum for best transient response. In the overdamped case the mechanical Q is less than 0.5 and the system has no tendency to oscillate. The acoustic response in the vicinity of resonance, however, decreases still further with decreasing Q.

Many sealed direct radiator systems are damped for best low frequency response which provides a maximum acoustic output down to a minimum frequency and a Q of about 1.

Damping is achieved mechanically, electrically, or acoustically or by a combination thereof i.e., by introducing power losses. Underdamping and overdamping are normally undesirable for high quality applications.

To maintain a flat response in a small sealed system having a resonance of 20 Hz and a Q of 1, would involve introduction of heavy moving mass in conjunction with heavy acoustic damping to flatten the response curve. Again a readjustment of parameters such as flux density, length of turns in the gap, etc. may be necessary for optimum performance. The efficiency of such a system may be very low over the entire range. The results could be improved but at the expense of increased cabinet volume. This implies that to achieve high level sound output involves expenditures of extremely high audio power over the entire audio range with correspondingly expensive equipment.

To accomplish flat acoustic response at low frequencies using a low frequency loudspeaker in a small sealed acoustically damped enclosure producing a response which is characteristic of the critical or overdamped cases (response rolls off prior to resonance and mechanical Q of 0.5 or less) coupled tightly to the power amplifier, said power amplifier having output source impedance less than 10 percent of the rated output impedance and compensation network located prior to said power amplifier, is the objective of the present invention. To accomplish this, a low frequency



loudspeaker is selected which is of high efficiency characteristic and it is operated in a sealed enclosure which exhibits high efficiency over the range, say, of 150–500 Hz. Such a speaker requires a very high flux density in the voice coil gap, long turns in the gap, low moving mass and low DC resistance. For the same power input, sound pressure levels above 150 Hz may be greater than corresponding levels produced by loudspeakers with higher effective mass and/or higher DC resistance.

The system resonant frequency, about 60 Hz, is established by the effective moving mass of the cone-voice coil assembly, acoustic reactance, and the acoustic environment in the cabinet. The mechanical Q is adjusted to a suitable value of 0.5 or less to provide an overall smooth rolloff. The rolloff of the response curve below 150 Hz approaches 6 dB per octave and gradually changes to 12 dB per octave below system resonance. This rolloff is compensated at the input to the power amplifier by enhancing drive power using an equalizer network. Effective compliance which determines the free air resonance of the loudspeaker mechanism is not critical as a change of plus or minus 10 Hz in free air resonance may produce only a 2 or 3 hertz change in system resonance. This change in system resonance will produce negligible change in acoustic output when used in accordance with the invention.

The loudspeaker mechanism must be capable of handling large amounts of power at low frequencies and consequently must be able to handle large excursions which occur at pressure peaks if flat acoustic pressures are to be maintained. This implies that the speaker cone assembly must be capable of wide excursions, say three-fourths inch, without damage to itself, and without the voice coil being moved entirely out of the magnetic gap. It also implies the linearity of the suspension mechanism as well as the linearity of the voice coil turns in relation to the magnetic gap flux be high to reduce non-linear distortion.

It is essential that the equalizer compensation network be located prior to the power amplifier to insure tight coupling between the output of the amplifier and the loudspeaker voice coil. In this way the compensation network remains isolated from the power amplifier output circuit. This insures that the internal impedance of the amplifier as seen by the speaker remains low (below **10%** of rated impedance) throughout the frequency spectrum when the speaker operates as a generator.

Although, the power amplifier with the compensation network connected antecedent to it appears not to be a constant voltage source with frequency, the power amplifier, in fact, continues to have the same low source impedance throughout the spectrum. This arrangement allows the shape of the equalization curve to be altered in any desired manner without affecting the damping of the loudspeaker. Insertion loss between amplifier and speaker must therefore, be avoided, as by avoiding compensation networks or even high resistance leads. A low frequency loudspeaker system arranged according to this invention can match acoustic output above 150 Hz with all higher frequency speakers to provide uniform wideband pressure response. Therefore, these latter can be operated at

high efficiency and it is a feature of the invention that the low frequency speaker system and higher frequency loudspeakers forming a complete wideband system are operated with high efficiency above 150 Hz in a common enclosure or in separate enclosures.

It is understood that it is old to compensate for loudspeaker rolloff by introducing compensation networks between the power amplifier and the loudspeaker, as in the U. S. Pat. to Corney No. 2,802,054 and the Wirth U.S. Pat. No. 3,061,676. It is also broadly old to introduce compensation at the input of an amplifier, as in Bose, U.S. Pat. No. 2,915,588, Bose U.S. Pat. No. 3,038,964 and Aceves U.S. Pat. No. 1,984,450.

None of these systems involve operation of a woofer and a high frequency loudspeaker in parallel, both operating at the same high efficiency, with heavy acoustic damping, the low frequency loudspeaker being electrically tightly coupled to the power amplifier to assure that the woofer follows the drive signal, and in which full compensation is provided down to about 20 Hz, and essential cut-off therebelow.

To assure correct operation the amplifier must look to the loudspeaker system like a constant voltage source but with frequency compensation. Below 150 Hz the amplifier output voltage must rise gradually to a maximum of 20 dB at 20 Hz. This rise is accomplished by the equalizer network prior to the power amplifier. The output impedance of the power amplifier must retain less than 10 percent of rated output load impedance.

Speaker lead lengths must be minimized and low resistance cable employed to connect the speaker to its driver. The woofer and its enclosure must also have a low Q of 0.5 or less, so that the rolloff curve remains simple. The speaker, down from about 150 Hz approaches a 6 dB per octave rolloff. Resonance occurs at about 60 Hz, and below resonance rolls off gradually increasing by an additional 6 dB per octave, for a total slope rate of 12 dB per octave. The compensation circuit can then employ two cascaded sections, of 6 dB per octave each, down to 20 Hz when enhancement is about 20 dB. Below this point the compensation network response is made to rapidly fall off, so that subsonic response of the system, below 20 cps, is negligible.

Although, the response curve is adjusted to be uniform at low frequencies when the system is radiating into a solid angle of 180°, the equalizer can be equipped with variable low frequency boost response which can be switched to maintain flat response when radiating into a solid angle of 90° or 45°. The reduced low frequency boost compensates for increased acoustical gains exhibited when the speaker radiates into the small solid angles.

## BRIEF DESCRIPTION OF THE DRAWING

The FIGURE is a block diagram of a system according to the invention.

## DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring now to the drawing, **10** represents a loudspeaker system containing loudspeakers to cover the entire audio spectrum. This system contains a low frequency loudspeaker which has high efficiency, and which has a low moving mass, low resistance, high gap flux density, and many turns in the gap. Such a loudspeaker might be 12 inches in diameter and have a 2 inch voice coil operating with a 54 oz. barium ferrite permanent magnet. The voice coil DC resistance may be 6.5 ohms and impedance at 400 Hz could be 10 ohms or slightly higher. Loudspeaker systems can be underdamped where they tend to oscillate, critically damped i.e., so damped they are on the verge of oscillating, or overdamped where there is no tendency to oscillate. The loudspeaker having low moving mass, low resistance, high flux density in the voice coil magnetic gap, and a long coil in the magnetic gap exhibiting a system Q of 0.5 or less is capable of following closely any audio signal applied to it and has no tendency to oscillate. The efficiency of the present loudspeaker system above 150 Hz may be higher than levels produced by a loudspeaker with higher effective mass and/or higher DC resistance.

The present low frequency loudspeaker is enclosed in an airtight or essentially airtight enclosure of 2 cubic feet. If plural low frequency speakers are used, 2 cubic feet of enclosure or more per speaker can be employed. For a single speaker 1,000 grams of fiberglass is used as acoustic absorbent material, having a density of ½ lb./cu. ft. This design produces a system resonance at 60 Hz. From 150 Hz rolloff approaches 6 dB per octave down to system resonance. Below system resonance rolloff gradually changes to 12 dB per octave. The mechanical Q of the speaker system at resonance is 0.5 or less. The acoustic damping which is introduced produces a smooth continuous response curve at resonance, lowers the system Q, lowers the system resonant frequency, and smooths out the response curve by reducing internal acoustic reflections. The loudspeaker efficiency above 150 Hz is high. Matching mid-range and high frequency loudspeaker, therefore, must also have high efficiency for a uniform wideband acoustical output.

Antecedent to the power amplifier, **12**, and following the preamplifier, **16**, is an equalizer network, **14**, which linearizes the response of the system by introducing a gain of about 20 dB at 20 Hz and decreasing at the rate of 12 dB per octave to system resonance at 60 Hz. From 60 Hz to 150 Hz the gain decreases to unity at the rate of 6 dB per octave. Below 20 Hz the gain is intentionally rolled off to eliminate unwanted subsonic frequencies.

In order to achieve a constant pressure response from this low frequency loudspeaker, voltage at its voice coil must rise with decreasing frequency to compensate for normal acoustic rolloff. This means the efficiency of the low frequency speaker decreases below 150 Hz since it requires more drive voltage or power at the lower frequencies.

Damping in the region of resonance is a function of the mechanical Q of the system which is directly proportional to the effective moving mass of the system and inversely proportional to the total resistance. Total resistance includes both acoustical and mechanical types. Associated with mechanical resistance is magnetic damping which is directly proportional to the square of the flux density in the magnetic gap and the square of the length of turns in the gap. Magnetic damping is inversely proportional to the total series re-

sistance which includes the resistance of the voice coil, resistance of connecting wires, and the power amplifier source resistance. Resistance, therefore, must be kept low commensurate with the desired system response. For a given loudspeaker system having a given DC resistance, acoustic resistance, mechanical suspension resistance, flux density, length of turns in the gap and effective moving mass, control of external variables is of extreme importance, namely lead resistance and power amplifier internal impedance. If appreciable resistance exists in the connecting leads, the voltage drop in these leads will decouple the speaker from the amplifier. Similarly, power amplifier impedance must be kept low. Theoretically, zero internal impedance is desirable but for practical application less than 10 percent of rated impedance will not significantly affect system performance. In the present invention leads of negligible resistance and a power amplifier of low internal impedance are employed to insure that the loudspeaker motion precisely follows the output voltage of the amplifier.

In summary, a small sealed loudspeaker system is described incorporating a low frequency loudspeaker which is critical or overdamped. Such damping is due to the action of the loudspeaker coil and magnet, other factors being equal. The magnetic structure must provide high flux density in the gap and long turns must exist in the gap. This type of damping does not reduce loudspeaker efficiency, but in fact high efficiency is a property of a speaker having high flux density and long turns. It is important that, in the present invention, damping is critical or over critical, with correspondingly high efficiency. An appropriate amount of acoustic damping is employed to smooth the rolloff of response in the region of system resonance and providing Q of 0.5 or less. An appropriate compensation network then drives the power amplifier such that rolloff of speaker response from about 150 Hz to 20 Hz is compensated for and response of the speaker system is flat over the entire audio spectrum down to 20 Hz. The output of the power amplifier is then at decreasing voltage response from 20 Hz up to 150 Hz, and constant acoustical pressures are produced over this range. The drive amplifier must have low resistance, as seen by the speaker, so that it looks like a voltage source i.e., has the same voltage for all speaker impedances, and to this end the drive circuit should have low resistance and any coupling between the amplifier and speaker must have as near zero resistance as feasible. This assures that precisely the voltage provided by the amplifier is present at the speaker coil, which can accurately follow the drive signal. Also, unless the speaker coil looks back into a low resistance it cannot provide the electrical damping required.

Input to equalizer **14** is provided by a preamplifier **16** having tone controls, and the preamplifier **16** is driven by a source of program material. The preamplifier itself may be assumed to have a flat response from 20 Hz to 20 kHz, and the lows are enhanced in a predetermined profile by the equalizer amplifier **14**, in voltage, and the net output of the speakers in terms of acoustic pressure is then flat.

The loudspeaker can be driven from a series push-pull amplifier where the output is taken off directly between the series transistor. The loudspeaker system will operate well from this type of amplifier meeting the low source resistance requirement. Other types of power amplifiers including the tube amplifier can be used as well provided the source resistance is less than 10 percent of the rated output impedance.

A typical loudspeaker for this application has a coil DC resistance of about 6.5 ohms. In a practical application, hook up wire and terminal connection resistance should be kept to less than 5 percent of the voice coil DC resistance. The source impedance of the power amplifier should be less than 10 percent of the amplifier rated output load impedance. Damping factor would then be greater than **10**. This will insure that a voltage source is present and not a current source. This damping factor must accrue down to 20 Hz, and the amplifier must be capable of supplying its rated power down to 20 Hz with low distortion.

Compensation can be adjustable to provide less boost when the speaker radiates into smaller solid angles than 180°. Additional variable mid-frequency and treble response boost or cut controls can be made a part of the equalizer to allow controlling or trimming the response of the overall speaker system.

I claim:

**1**. A loudspeaker system including a compensation network, a power amplifier having flat response from 20 Hz to at least a mid-range audio frequency, a loudspeaker system arranged to maintain a level acoustic response down to 20 Hz, said loudspeaker system comprising at least one electrodynamic bass loudspeaker having a voice coil, said compensation network comprising an equalizer amplifier arranged to increase the drive of said power amplifier as a function of frequency so as to compensate for rolloff by about **6** db per octave to system resonance and thereafter by about **12** db per octave down to about 20 Hz with sharp cut-off thereafter, said power amplifier having a predetermined output circuit resistance as seen by said loudspeaker system which is sufficiently low that said output circuit acts as a voltage source for a loudspeaker load directly connected thereto such that said power amplifier provides essentially constant output voltage at all output currents, said power amplifier being capable of delivering its rated power with flat response down to said about 20 Hz, a loudspeaker system including said bass loudspeaker and a high frequency loudspeaker of acoustic efficiency equal to the acoustic efficiency of said bass loudspeaker, said loudspeakers being connected in electrical parallel to said power amplifier to be driven thereby, leads having resistance less than 5 percent of the dc resistance of said loudspeaker system connecting said power amplifier to said bass loudspeaker, said bass loudspeaker system comprising a sealed enclosure, acoustic damping material in said enclosure, said low frequency loudspeaker having concurrently sufficiently low effective moving mass, low resistance and high flux density, and said enclosure acoustic damping material providing adequate acoustic damping to provide a system Q at about 0.5 or less at a resonant frequency of about 60 Hz with consequent substantially smooth roll-off of acoustic pressure provided by said loudspeaker from about 150 Hz to 20 Hz, said loudspeaker system being mechanically capable of achieving uniform sound pressure response through its range down to 20 Hz, said compensation network being

connected to the input of said power amplifier for compensating for said acoustic pressure roll-off of said loudspeaker system down to said 20 Hz, so as to provide flat acoustic pressure response down to said 20 Hz.

2. An audio system, including a voltage compensation network, an audio power amplifier having flat response over a range from 20 Hz to at least a mid-range audio frequency, a loudspeaker system capable of supplying a level acoustic pressure response over mid-range down to 20 Hz, said loudspeaker system comprising at least one electrodynamic bass loudspeaker having a voice coil, said compensation network comprising an equalizer amplifier arranged to increase the drive of said power amplifier as a function of frequency so as to compensate for acoustic pressure roll-off of said loudspeaker system by about 6 db per octave to the resonance frequency of said loudspeaker system and thereafter by about 12 db per octave down to said 20 Hz with sharp cut-off thereafter, said power amplifier having a predetermined circuit resistance as seen by said loudspeaker system which is sufficiently low that said power amplifier acts as a voltage source for any loudspeaker load directly connected thereto so that said power amplifier is a voltage source as seen by said bass loudspeaker, said power amplifier being capable of delivering at least its rated power with said flat acoustic pressure response down to said about 20 Hz, said loudspeaker system including said bass loudspeaker and also including a high frequency loudspeaker of equal high acoustic efficiencies connected in electrical parallel to said power amplifier to be driven thereby, leads having resistance of less than 5 percent of the dc resistance of said loudspeaker system directly connecting said power amplifier to said bass loudspeaker, said loudspeaker system comprising a sealed enclosure of about two cubic feet per bass loudspeaker, acoustic damping material in said enclosure, said bass loudspeaker having concurrently sufficiently low effective moving mass, low resistance and high flux density, and said enclosure and acoustic damping material providing adequate acoustic damping to provide a system Q at about 0.5 or less at a resonant frequency of about 60 Hz with consequent substantially smooth roll-off of acoustic pressure provided by said loudspeaker from about 150 Hz to 20 Hz, said loudspeaker system being mechanically capable of achieving uniform sound pressure response through its range down to 20 Hz when suitably driven, said voltage compensation network being connected to the input of said amplifier for compensating for said acoustic pressure roll-off of said loudspeaker system down to said 20 Hz so as to provide constant acoustic pressure response of said system over the range of said bass loudspeaker in said audio system down to said 20 Hz.

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