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(54) Cable and apparatus connected thereto

(57) There is provided apparatus and a cable, with the cable including a plurality of conductors located therealong and at least one screen, the screen is provided to be conductive and the at least one screen is connected to a power source such as an auxiliary amplifier which supplies power thereto. The conductors are connected to a main amplifier which supplies power thereto. The provision of a controlled power supply to the at least one screen in addition to the conductors allows the performance of the cable and the apparatus as a whole to be improved. The cable can be provided for any use but use with audio apparatus is one example to where significant improvements can be obtained.

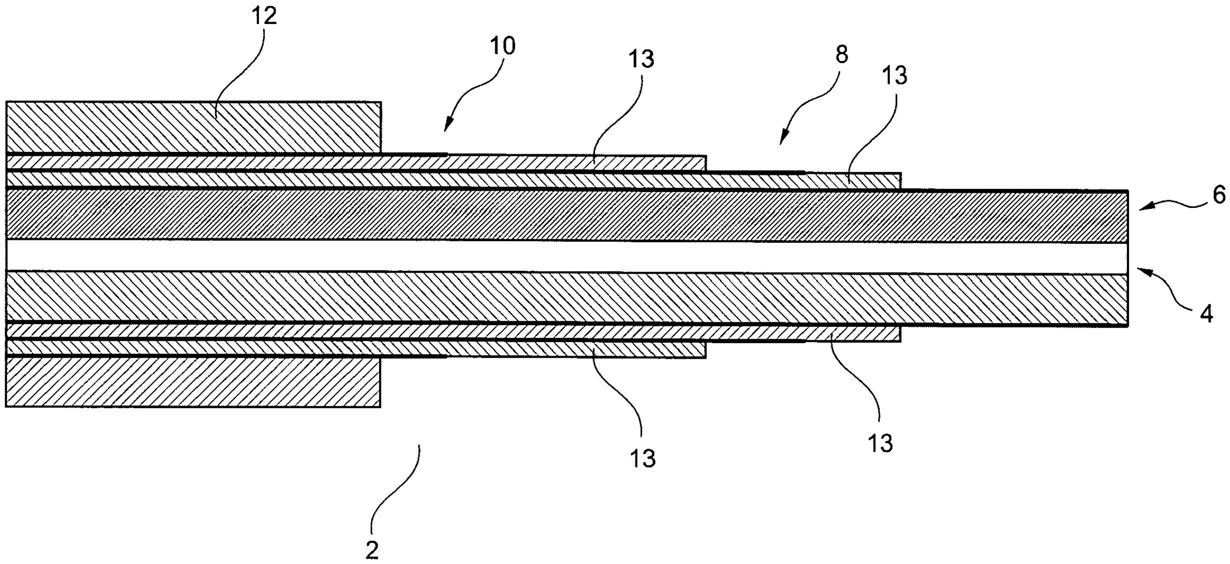

Fig. 1a

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Description

[0001] The invention which is the subject of this application relates to cables and the provision of apparatus and/or devices to control the same so as to improve their performance such as to reduce the level of signal loss which occurs when in use. In particular, although not necessarily exclusively, the cables are provided for use as interconnect cables and, yet further, for connecting one or more loudspeakers to a source of audio, such as an amplifier.
[0002] Conventionally, when designing cables, there are three main features to take into account, these being; DC resistance, which is created by the specific design of the cable and the conductors running therealong; loop inductance which can typically be affected by the spacing of the conductors in the cable, and shunt capacitance. The shunt capacitance both loads the power amplifier and contributes to a distributed current throughout the length of each conductor constituting the cable. An aim when designing cables is to move the conductors together to reduce the loop inductance which is created. However this tends to have an adverse effect on the shunt capacitance which, in turn, adversely affects the amplification and current which is required. As a result of these interlinked design pressures and constraints, it is typically the case that any cable design will represent a compromise which has been reached and accepted in order to obtain a cable with acceptable DC resistance, loop inductance and shunt capacitance values.
[0003] An aim of the present invention is therefore to provide a form of cable which, when used, exhibits less signal loss than the equivalent conventional cable designs, while, at the same time, reducing the dependence on the cable shunt capacitance, including properties of the dielectric insulator which is used to separate the conductors forming the cable, and of signal loss due to the distributed capacitive charging current in the conductors. A further aim is to provide control means for use in conjunction with the cable which allows the optimum performance of the cable to be achieved, while, at the same time, avoiding the need for relatively complex and/or expensive additional apparatus to be used. A further aim is to provide a cable and associated apparatus therefore which exhibits an improvement in performance which can be subjectively detected.
[0004] In a first aspect of the invention there is provided apparatus including a cable, said cable including at least first and second conductors running along the length thereof, and wherein there is provided one or more screens located within the cable, with at least one of the screens located between the first and second conductors and wherein at least one of said screens is connected to means to provide power thereto during usage of the cable to carry signals and/or data therealong.
[0005] Typically the one or more screens are formed from, or include, a conductive material.
[0006] In one embodiment the means to provide power is an amplifier, said amplifier typically provided within, or in connection with, apparatus to which at least one end of the cable is connected.
[0007] In one embodiment at least one of the conductors is connected to an amplifier.
[0008] In one embodiment a single screen is provided and in one embodiment the voltage level of the power supplied to the screen and the voltage level of the power supplied to said at least one conductor are substantially the same.
[0009] I n another embodiment two or more screens are provided and in one embodiment the voltage level of the power supplied to a first screen and the voltage level of the power supplied to a first conductor are substantially the same, while the voltage level of the power supplied to a further screen is substantially the same as the voltage level of the power supplied to a further conductor.
[0010] Typically the cable is used for audio purposes and the passage of audio signals or data therealong.
[0011] In one embodiment, the amplifier connected to the at least one screen is provided as an auxiliary amplifier for connection with a main amplifier to which at least one conductor is connected, and/or the auxiliary amplifier is provided as an integral part of the main amplifier.
[0012] In one embodiment the screen is connected with the auxiliary amplifier via a plug or socket termination at one end of the cable, said plug or socket then connectable with the amplifier apparatus to allow the power to be supplied thereto and, in turn the at least one screen and/or at least one connector.
[0013] In one embodiment the first and second conductors are arranged in a co-axial configuration along the cable and the screen is located intermediate or between said conductors and is annular in cross section.
[0014] Typically, the conductors employed in said co-axial cable can either be of solid form or made up of a weave of fine conductors, including conductors of differing diameters, to form a composite multi-stranded conductor offering improved flexibility. These individual strands of the weave may also be insulated from each other so as to form a composite conductor commonly called a "Litzendraht" or Litz wire.
[0015] In one embodiment the first and second conductors each have individual insulated and closely spaced coaxial screens to form two compound conductors and the two compound conductors are then twisted together in close proximity. The close spacing helps to achieve low inductance while the twisting action lowers the susceptibility to electromagnetic interference.
[0016] In both the coaxial construction and twisted pair construction, multiple cables can be connected in parallel to further lower dc resistance and loop inductance.
[0017] It is found that by providing a cable in accordance with the invention, the conductors of the cable can be placed

closer together than would conventionally be possible, thereby reducing loop inductance whilst, at the same time, ensuring that the shunt capacitance and DC resistance are not a problem. It is found that, in turn, any series losses which are experienced can be of an order of magnitude less than those with conventional cable designs and the error signal between the input and the output of the cable is significantly reduced.

[0018] The screen or screens can typically be formed from any or any combination of foil, metallised mylar foil, braid and conductive materials such as copper, silver or the like.

[0019] In a further aspect of the invention there is provided a cable including an insulated screen located between at least two conductors substantially along the length of the cable and wherein said screen is connected to a power supply during operation of the cable.

[0020] In a further aspect of the invention there is provided a cable including at least two screens located between at least two conductors along the length of the cable and wherein one of said screens is connected to a power supply during operation of the cable while the other of said screens is connected to a ground connection at an input or output to or from the cable.

[0021] Typically the screens are insulated.

[0022] In a further aspect of the invention there is provided a cable for balanced operation said cable including at least two insulated screens located between at least two conductors along the length of the cable and wherein one of said screens is connected to a power supply while the other said screen is connected to a second power supply during the operation of the cable.

[0023] Typically the power supply to at least one of the screens is provided from an amplifier which is a different amplifier to that which supplies power to at least one of the conductors. Typically the said amplifiers are controlled to provide substantially the same voltage levels to the screen and at least one conductor respectively.

[0024] In one embodiment a dc polarizing voltage is added to one or more of the screens as well as an ac signal.

[0025] In a further aspect of the invention there is provided a cable having a plurality of conductors therealong and one or more screens located between at least two of the said conductors, said screens provided with power from one or more amplifiers and at least one of the conductors provided with power from a further amplifier and wherein the voltage drop is substantially zero.

[0026] In a further aspect of the invention there is provided apparatus for use in the control of the operation of a cable, said apparatus including a first amplifier to be connected to at least one conductor of the cable and wherein the apparatus includes a further amplifier for connection to a screen located in the cable.

[0027] A further embodiment of the invention is to use two screens located between the two conductors such that by using said further or auxiliary amplifier the two dielectric regions between each conductor and screen can operate either with a zero polarizing electric field or with a constant polarizing electric field.

[0028] In one embodiment, when two screens are used and the cable is operated in a single-ended mode, then only one further or auxiliary amplifier is required with the other screen being connected to ground at only one end of the cable.

[0029] In one embodiment, when two screens are used and the cable is operated in balanced mode, then two further or auxiliary amplifiers are required. In addition, if the cable is surrounded by an external electrostatic shield held at ground potential (a common practice to lower susceptibility to electromagnetic interference), then a third screen can be used between the outer conductor and shield. As such, the outer most conductor (assuming for illustration a co-axial construction), would have screens located on either side where these two screens are connected together and powered from a common auxiliary amplifier.

[0030] In one embodiment, in order to engender a symmetrical cable construction, two or more cables of substantially identical construction can be connected in parallel and with the wiring between the respective inner and outer conductors cross coupled.

[0031] In an alternative embodiment, the two conductors can have individual outer coaxial screens with insulation either side of each screen where the two cables are twisted together with close spacing to reduce loop inductance. Typically, this form of cable can be used either for single ended or balanced operation.

[0032] In one embodiment, a complex or weave of a plurality of small diameter conductors can be formed, each conductor provided with an associated outer screen, and an intertwined/platted or Litz wire construction of multiple send and return wires can be constructed. Such a construction improves the distribution of current and, assuming fine conductors, greatly reduces skin-depth effects.

[0033] In one embodiment the amplifiers are provided within a common housing. Alternatively the auxiliary amplifier is provided to be selectively connected to apparatus including the first or main amplifier.

[0034] Typically the connection of the cable with the apparatus is via a plug and socket assembly which allows the supply of power from the amplifiers of the apparatus to the conductor and screen.

[0035] Typically, the apparatus includes control means to ensure that the supply of power occurs automatically when the apparatus is switched on and, furthermore, to ensure that the screen is driven by the power from its amplifier at substantially the same voltage level as that of the conductor connected to the other amplifier.

[0036] In one embodiment the conductors are any, or any combination of, braid, stranded and/or foil. The screen is typically provided to be flexible and can also be used to maintain the spacing between the conductors within the cable. Typically the auxiliary amplifier used for the screen has an output voltage sweep which is at least equal to or greater than that of the main amplifier. Typically the current which is supplied is determined by the length of the cable in question and the shunt capacitance so that, in operation, the auxiliary amplifier is linear and remains unconditionally stable.

[0037] In one embodiment a plurality of cables of the type described herein are provided to interconnect apparatus, typically audio apparatus, such as, for example to connect loudspeakers to an amplifier. In one embodiment the screens in the respective cables are connected to a common auxiliary amplifier.

[0038] In accordance with the invention there is provided a cable with one or more electrical screens within the audio cable which are driven by an auxiliary amplifier such that the cable shunt capacitance is effectively lowered. This expedient allows the main or conventional conductors of the cable which are used to transfer audio and/or video and/or other data signal through the cable to be in close proximity to significantly reduce the loop inductance. As such a cable can be realized which has both low shunt capacitance and low series losses.

[0039] In one embodiment there is provided an audio cable with a single electrical screen placed between the main conductors and fed by a unity-gain auxiliary buffer amplifier which derives its input signal from the input voltage to the cable. Conductors and screens are electrically insulated using a dielectric material.

[0040] In a further embodiment there is provided an audio cable with two electrical screens placed between the main conductors. The screen closest to the positive or out conductor is fed from a unity-gain auxiliary buffer amplifier which derives its input signal from the input voltage to the cable while the screen closest to the cold or return conductor is connected to ground at the input end of the cable.

[0041] The ability to keep the conductors in close proximity is highly instrumental in reducing susceptibility to electromagnetic interference and this principle applies universally to all cable examples cited in this application.

[0042] Typically the auxiliary amplifier which is typically operated as a unity-gain amplifier can be either manufactured as an external unit or integrated into an amplifier system. Such a configuration can be adapted for both single-ended and balanced operation.

[0043] In whichever embodiment the auxiliary amplifier is preferably provided such that it has an output voltage swing or range that is greater than the output voltage swing or range of the main amplifier. Typically a voltage gain close to one to a frequency significantly above the audio band is maintained in operation of the apparatus

[0044] Typically the apparatus includes a plug and socket connector assembly that contains three or more pins for connection of power via first and second connectors to the first and second conductors and at least one further connector for the connection of power to at least one screen of the cable. Typically a connector will be provided for each of the screens of the cable and the number of connectors used will depend on the number of screen in the cable connected to the amplifier apparatus at that time. In one embodiment the connector assembly is non-reversible and therefore guarantees correct phasing and connection to main conductors and screens. Typically in this embodiment. In one embodiment the conductors in the cable are provided to be coaxial or alternatively the conductors are twisted around each other. A cable construction in accordance with the above claims where hot and cold conductors are constructed using a weave of fine conductors in a litz construction and where each composite conductor is surrounded by an electrical screen. The composite cables are then twisted together. The spacing between screens and conductors should be kept small to minimize loop inductance. Conductors and screens are electrically insulated using a dielectric material. In one embodiment the conductors are constructed using a weave of fine conductors in a litz construction and each individual conductive strand is surrounded by a closely spaced electrical screen. The composite cable is then constructed by interweaving the individual strands. The screens are separately connected together at the input of the cable.

[0045] Typically the above cable geometries can be adapted for balance operation.

[0046] In one embodiment an additional outer screen can be used so in a coaxial construction the outer conductor has screens flanking both inner and outer surfaces and where these screens are driven in parallel.

[0047] Typically the cable geometries can be adapted for both low-level and high level applications thus becoming appropriate for low-level signal applications such as connecting a preamplifier to a power amplifier as well as high-level applications such as connecting a power amplifier to a loudspeaker.

[0048] In on embodiment multiple cables can be combined in parallel to lower series losses still further. In such a construction where each cable is coaxial, then conductors can be interchanged to achieve greater symmetry.

[0049] Typically the apparatus can be adapted for bi-and tri-wiring type systems where the individual drive units of a loudspeaker are supplied by individual cables. In such a system all cables receive the same input voltage therefore only a single unity-gain buffer amplifier is required providing it can supply current for the total capacitance of multiple cables.

[0050] In a further aspect of the invention there is provided apparatus including an amplifier and a cable for connection at one end to the amplifier and, at the other end to an item of apparatus to receive and/or transmit data and/ or signals via the cable, said cable including at least one screen located substantially along the length of the cable, wherein said at least one screen is connected to receive power from a power supply during use of the cable, so as to reduce the impact of any or any combination of DC resistance, loop inductance and/or shunt capacitance

[0051] Specific embodiments of the invention are now described with reference to the accompanying drawings wherein

Figure 1a illustrates a longitudinal cross sectional view of a cable with a single screen in accordance with one embodiment of the invention.

Figure 1b illustrates a longitudinal cross sectional view of a cable with two screens in accordance with another embodiment of the invention.

Figures 1c-e illustrate apparatus according to embodiments of use of the invention;

Figure 2 illustrates a schematic diagram of the cable and amplifier apparatus in accordance with one embodiment of the invention;

Figure 3 illustrates the embodiment of Figure 2 including a discrete transistor unity-gain amplifier;

Figure 4a-b illustrate a further embodiment of a cable in accordance with the invention;

Figure 5 illustrates an embodiment of an auxiliary amplifier in accordance with an embodiment of the invention.

Figure 6a illustrates a balanced active low-level cable with differentially driven unity-gain amplifiers formed using operational amplifiers in accordance with the invention in one embodiment;

Figure 6b illustrates two examples of balanced active high level cable with differentially driven unity-gain amplifiers in accordance with the invention in one embodiment;

Figure 6c illustrates a multi-screen and outer shield coaxial cable for single ended high level applications;

Figure 6d, e, f illustrate 3 configurations of multi-screen and outer shield coaxial cables for high level balanced applications;

Figure 7 illustrates a bi-wired apparatus embodiment in accordance with the invention;

Figure 8a illustrates a corrective feedback circuit for series cable losses in accordance with one embodiment of the invention;

Figure 8b illustrates a cable with additional sense wires to measure cable losses in accordance with one embodiment of the invention;

Figure 9 illustrates an active cable correction system in accordance with one embodiment of the invention;

Figure 10 illustrates a low-level pre-amplifier application using a unity-gain buffer amplifier to drive the cable screen in accordance with another embodiment of the invention; and

Figure 11 illustrates a low-level pre-amplifier application using unity-gain buffer and dc polarization to drive the cable screen in accordance with another embodiment of the invention.

[0052] Referring firstly to Figures 1c-e there is illustrated, schematically, apparatus in accordance with the invention. In each of the Figures 1c-e there is shown a main amplifier 100 which is provided to be connected to at least one of the conductors in the cable 102 which connects the amplifier 100 to, in this case, speaker 104. In each case and in accordance with the invention there is provided an auxiliary amplifier 106.

[0053] In Figure 1c the auxiliary amplifier 106 is provided as an integral part of the main amplifier 100 and in Figures 1d and e the auxiliary amplifier 106 is connected to the main amplifier 100 by connector 110.

[0054] In Figure 1c the cable 102 conductors and at least one screen are connected to the main and auxiliary amplifiers respectively to receive power therefrom, via a common three or four pin socket 112 with the auxiliary amplifier located within the main amplifier as an integral part thereof.

[0055] In Figure 1d the cable 102 conductors are connected to the main amplifier 100 via adaptor 114 and arm connection 116 which passes to the main amplifier 100 and the adaptor also allows connection of the at least one screen of the cable to the auxiliary amplifier 106 via arm connector 118.

[0056] In Figure 1e the cable 102 conductors are directly connected to the main amplifier 100 via plug or socket 120 and the at least one screen 122 of the cable is separated from the conductors at the end of the cable to a sufficient degree to allow the same to be connected to the auxiliary amplifier 106 via plug or socket 124.

[0057] It will therefore be appreciated that Figure 1c is particularly suited for implementation in a product which is sold as a new "integrated" product , whereas the embodiments of Figures 1d and e can be provided as retrofit products with the auxiliary amplifier and possibly an adaptor provided to be bought and then connected to an existing amplifier to allow the advantages of the cable performance of the invention to be achieved.

[0058] Although the invention is described with reference to use in connection of an amplifier to audio apparatus in the form of one or more speakers, it should be appreciated that a cable in accordance with this invention can be used for further items such as the transfer of video data between items of apparatus. Referring now to Figure 1a there is illustrated a portion 2 of a length of cable formed in accordance with one embodiment of the invention and shown in cross section along it’s longitudinal axis. The cable includes a hollow core 4, which is surrounded by a first conductor 6. This, in turn, is surrounded by a screen 8, and that is enclosed within a second conductor 10 such that the screen acts to separate the two conductors in a manner to ensure that the relative proximity of the first and second conductors does not adversely affect the performance of the cable. The cable conductors and screen are enclosed by a sheath 12.

[0059] The cable can be terminated at at least one end with a plug or socket (not shown) which allows the first (or hot) conductor 6 to be connected to an amplifier and the screen 8 to be connected to another amplifier such that power can be supplied to both the conductor and screen, with the voltage of both supplies being such that there is a substantially zero voltage drop between the conductor and the screen.

[0060] As a consequence of this embodiment, the electric field within the dielectric material between hot conductor and screen is either zero or constant if a dc polarization voltage is included. As a result of this the performance dependence upon dielectric imperfections is greatly reduced. This is an additional feature to that of the low loop inductance which is achieved.

[0061] In a further embodiment of this invention a cable of coaxial construction as shown in Figure 1b employs two coaxial screens (items 8a and 8b) located between the hot conductor 6 (normally the inner most conductor) and cold conductor 10 (normally the outer most conductor). The screen 8b adjacent to the hot conductor is supplied with power from an auxiliary unity-gain amplifier while the screen 8a adjacent to the conductor is connected to a ground connection such as the ground loudspeaker output of the main amplifier which is connected to at least one of the conductors to supply power thereto. This connection means that the dielectric insulator 13 between each conductor and its associated screen operates with a zero or constant value electric field. As a consequence of this arrangement there is no capacitive charging current at the input of the cable and neither is there current in the two main conductors resulting from the distributed ac signal current charging the shunt capacitance of the cable. This is important for three reasons, firstly, loading on the power amplifier due to cable shunt capacitance is reduced or eliminated, secondly, the error voltage across each conductor arising from the capacitive charging current is also eliminated, and thirdly any dielectric imperfections do not affect the transfer of signal from source to destination. Because the driven cable shunt capacitance resides solely between screen 8a and screen 8b then the auxiliary amplifier provides the required charging current and, as such, isolates this aspect of the cable.

[0062] An auxiliary power amplifier is connected to the screen 8 in Figure 1 a and to the screen 8b in Figure 1b and it is able to produce a wide output voltage swing, having a wideband gain close to unity and be capable of outputting sufficient current to drive the cable capacitance between the internal conductive screen (8 in Figure 1a or 8b in Figure 1b) and outer cold conductor 10 in Figure 1a or outer screen (item 8a) in Figure 1b. Furthermore, as the amplifier does not introduce a signal directly into the cable path then its performance (from an audio perspective) is less critical than the main amplifier used to drive the loudspeaker load via the conductors.

[0063] Two options for accommodating the auxiliary amplifier are possible: firstly in which the amplifier is a standalone system designed for use with any power amplifier and second, in which it is an integrated feature within a power amplifier. The latter option eliminates the need for a separate power supply and can therefore provide a lower cost option as well as being more convenient for the user.

[0064] Where the auxiliary unity-gain amplifier is integrated within the power or main amplifier for the conductors; the only external difference is that the power amplifier output socket to the cable is a 3-wire connector. If used with a conventional cable the screen output from the amplifier can be left disconnected which facilitates conventional two-wire operation. Alternatively, the screen and hot conductors can be connected together to allow the main amplifier to provide the charging current to the screen as well as the current demanded by the loudspeaker. This latter connection retains the desirable property that the cable dielectric operates with a zero or constant value of electric field although the main amplifier now has to provide the charging current for the cable. In another embodiment the unity gain amplifier can be included as an integral part of the cable assembly.

[0065] The concept in one embodiment is presented in the system diagram shown in Figure 2 in which there is shown apparatus 14 including a main amplifier 12 and an integral auxiliary amplifier 18 which both supply power to socket 20 to which a cable 2 in accordance with the invention is connected at one end 22, and at the other end 24 to loudspeaker 26.

[0066] An important parameter in operation is the voltage gain of the auxiliary amplifier where this needs to be close to unity and maintained over a bandwidth from dc to well in excess of the audio band.

[0067] In most power amplifiers it is common to include a series Zobel network as an aid to stability. This however creates a dilemma as to where to derive the input for an integral auxiliary amplifier. An important factor is to maintain the voltage between the "live" loudspeaker conductor and screen very close to zero. As a consequence, the input voltage should preferably be derived from the "loudspeaker end" of the Zobel network as illustrated in Figure 3.

[0068] Feedback in the conventional amplifier is derived in the normal way where the performance of this amplifier is not influenced by the unity-gain amplifier. This embodiment of the auxiliary amplifier, as a discrete transistor auxiliary amplifier, shown for purposes of illustration, has its own local feedback loop and achieves a wide-band voltage gain extremely close to unity. An output-stage bias current of around 10 mA is chosen to achieve good power efficiency while local feedback facilitates both low distortion and a closed loop gain close to unity.

[0069] In another embodiment a simpler cascaded emitter follower stage can be provided as output resistance is not critical.

[0070] There are now provided examples of operation of a cable employing a single screen in accordance with the invention and in which a single length of co-axial cable in accordance with the invention has been used.

Example 1

[0071]

Relative permittivity of dielectric	1.5
Capacitance between inner conductor and screen	2.289 nano-farad
Capacitance between screen and outer conductor	2.916 nano-farad
Series inductance of cable	0.405 micro-henry
Capacitive reactance of C_1 at 20 kHz	3.477 kohm
Capacitance reactance of C_2 at 20 kHz	2.729 kohm
Inductive reactance of L_s at 20 kHz	0.051 ohm
DC loop resistance of cable	0.002 ohm
Overall length of cable	5 m
Radius of inner conductor	R_1 = 5.00 mm
Radius of screen	R_2 = 6.50 mm
Radius of outer conductor	R_3 = 9.00 mm
Radial thickness of inner conductor	r_1 = 4.50 mm
Radial thickness of screen	r_2 = 0.50 mm
Radial thickness of outer conductor	r_3 = 1.50 mm
Radial thickness of each dielectric within cable	a_{gap} = 1.00 mm

Example 2

[0072]

Relative permittivity of dielectric	1.5
Capacitance between inner conductor and screen	4.796 nano-farad
Capacitance between screen and outer conductor	5.631 nano-farad
Series inductance of cable	0.241 micro-henry
Capacitance reactance of C_1 at 20 kHz	1.659 kohm
Capacitance reactance of C_2 at 20 kHz	1.413 kohm
Inductive reactance of L_s at 20 kHz	0.030 ohm
DC loop resistance of cable	0.002 ohm
Overall length of cable	5m
Radius of inner conductor	R_1 = 5.50 mm
Radius of screen	R_2 = 6.50 mm
Radius of outer conductor	R_3 = 8.50 mm
Radial thickness of inner conductor	r_1 = 2.85 mm
Radial thickness of screen	r_2 = 0.50 mm
Radial thickness of outer conductor	r_3 = 1.5 mm

(continued)

Radial thickness of each dielectric within cable	a_{gap}= 0.50 mm

Example 3

[0073]

Relative permittivity of dielectric	1.5
Capacitance between inner conductor and screen	3.961 nano-farad
Capacitance between screen and outer conductor	4.796 nano-farad
Series inductance of cable	0.288 micro-henry
Capacitance reactance of C_1 at 20 kHz	2.009 kohm
Capacitance reactance of C_2 at 20 kHz	1.659 kohm
Inductive reactance of L_s at 20 kHz	0.036 ohm
DC loop resistance of cable	0.003 ohm
Overall length of cable	5m
Radius of inner conductor	R_1 = 4.50 mm
Radius of screen	R_2 = 5.50 mm
Radius of outer conductor	R_3 = 7.50 mm
Radial thickness of inner conductor	r_1 = 4.5 mm
Radial thickness of screen	r_2 = 0.50 mm
Radial thickness of outer conductor	r_3 = 1.5 mm
Radial thickness of each dielectric within cable	a_{gap} = 0.50 mm

[0074] The provision of the cable as a co-axial cable is shown in Figures 1a and b. However there are other possible designs which could be used. An example of an alternative cable construction is shown in Figures 4a-b.

[0075] Figure 4a shows a short arc 30 of the cross section of the cable design 32 of Figure 4b and, in practice, the pattern of the arc 30 is repeated to form a regular interleaved braid that is curled around to form a regular cylindrical construction as shown schematically in Figure 4b. The conductor braid consists of interleaved conductive strands which are separated by a thin layer of dielectric (preferably aerated PTFE), and then each strand, together with its dielectric, is encapsulated by the conductive screen.

[0076] The conductors 6, 10 as shown in Figure 4a have rectangular cross-sections to enable close spacing of adjacent conductors which is helpful in being able to achieve a low value of loop inductance in the active cable concept; also, the screen must be located in close proximity to all conductors. However, when the construction takes on a cylindrical geometry then ideally each conductor should be trapezoidal in shape (i.e. wedge shaped) to enable smooth curvature while retaining close conductor proximity necessary to minimize the series inductance.

[0077] The cable structure allows the "send" and "return" conductors to alternate between the inside and the outside of the cable cylinder thus achieving perfect symmetry. In addition this topology also means there will be reduced susceptibility to induced interference from magnetic fields in a way that is similar to twisting a pair of conductors. The total encapsulation of each conductor by the screen also contains the electric field.

[0078] By using a multi-strand construction with, for example, PTFE insulation, not only are the dielectric properties ideal for audio but the PTFE acts as a dry lubricant against each conductor to facilitate flexibility by aiding relative motion between conductors when the overall cable is curved.

[0079] Although it is shown that each conductor in the cables is solid core, in another embodiment the individually screened conductors are synthesised by a tightly packed formation of fine conductors.

[0080] In one embodiment the central core of the cable is packed with a solid or hollow strand of polythene in order to provide additional strength and to maintain structural integrity as shown in Figure 1a. When hollow, the core, in any of the designs of cable may be used to allow the passage of sensors and connections therefore in order to allow the operation of the cable to be monitored.

[0081] Figure 5 illustrates an example of an auxiliary power amplifier 18 for use to drive at least one screen of the cable. This amplifier should have unity gain and obtain its input from the "live" output terminal of the power amplifier. The output current demand of this amplifier is not large and is determined by the rate of change of output voltage and the cable capacitance between screen and the "ground" conductor. However, the output voltage swing needs to be sufficiently high such that it is greater than the highest voltage swing encountered in domestic audio systems. It is proposed that a peak to peak voltage swing of -65 V to 65 V should meet most requirements.

[0082] The auxiliary amplifier 18 in this embodiment is essentially a cascade of three complementary emitter-follower amplifiers that are biased by the group of complementary transistors shown in the area 28 indicated by broken lines . These four bias transistors can be formed from an integrated array because, ideally, both parametric matching and thermal tracking are required.

[0083] The four transistor array has a dual function: Firstly, in association with two complementary current sources (each locally biased by transistors and red LEDs), the logarithmic characteristic of a transistor is exploited so that a derived bias voltage facilitates smooth current transition between the output transistors. If it is appreciated that under quiescent conditions, all four transistors nominally carry the same collector current that is equal to the current provided by the two complementary current sources, then dc bias conditions can be designed. Secondly, the array acts as a complementary differential stage employed as part of an output-voltage derived negative feedback loop.

[0084] The circuit also shows a series connection of eight Silicon diodes 30. Normally these do not conduct and are provided to act as a fail-safe limit to the maximum bias voltage which is used to set the output device bias current.

[0085] A series input resistor is shown as a means of protection if either the amplifier is over driven or driven with the power supply turned off.

[0086] For practical cables and output voltage swings the amplifier is unlikely to output current that is greater than 100 mA so the output transistors can be wide-band medium power devices with appropriate secondary breakdown characteristics, biased to keep quiescent power dissipation low. This implies the power supply only has to have moderate output current capability and because of the unity-gain feedback arrangement, supply ripple should not be a significant problem. Also, reservoir capacitors still remain modest in value even if 10000 times the output-load capacitance. More important is maintaining stability into a capacitive load and maximising bandwidth. The use of emitter follower circuitry together with fast acting local feedback can achieve a wide bandwidth.

[0087] The cable constructions discussed have been directed at use for unbalanced operation. In practice unbalanced operation of cables will represent the majority of domestic audio systems; however there are a minority of systems that use balanced connections for both low level preamplifier interconnections and for power amplifier loudspeaker interconnections. Figure 6a,b shows three examples of systems of this type. In Figure 6a the system is configured for low-level signal applications and uses two operational amplifiers 34, 36 with series negative feedback to implement the two unity-gain buffers, while in Figure 6b, two embodiments are shown for loudspeaker applications which differ mainly in the way the cable and screens are constructed. In the balanced mode as depicted in Figures 6a,b two individual, closely spaced and twisted active cables 38, 40 can be used or, in the preferred embodiment, a single coaxial cable 42 incorporating two screens is utilised. The balanced system requires two unity-gain auxiliary amplifiers that are driven differentially from the balanced output of an amplifier system. The function of each auxiliary amplifier is to provide the charging current for the cable capacitance, where it is critical that each screen potential follows that of its associated active conductor. Maintaining close physical proximity between the conductors reduces loop inductance. In addition, the dielectric material between each signal conductor and screen then operates with zero electric field (or a constant field if a polarization voltage is used) while the third dielectric segment is isolated by the two auxiliary amplifiers. These expediencies, which affect both electric and magnetic fields within the cable, help to significantly reduce performance dependence on cable characteristics.

[0088] Figure 6c,d,e,f show examples of multi-screen cables 50 for balanced operation in accordance with further embodiments of the invention that use a coaxial cable construction with multiple screens together with an additional outer electrostatic shield which is normally connected either to ground (at the power amplifier end of the cable) or left floating (unconnected).

[0089] In Figure 6c a single ended cable 70 is shown and, in this case, as the outer conductor 72 is maintained at ground potential, there is no potential difference between this conductor 72 and the outer electrostatic screen 74. Furthermore no auxiliary amplifier is required to be used and the main amplifier is used to drive both the hot conductor 76, also referred to as the live conductor, and its screen 75.

[0090] In Figures 6d,e,f the cable shown in each case is configured for balanced operation. The power amplifier 81 produces two complementary output voltages V_1 and V_2 that swing symmetrically about ground potential and where $V_1 = -V_2$. The cable in Figure 6d has three screens, two 80,82 located between the first and second conductors 84,86 and a third 88 between the second conductor and the outermost shield 90. The screens are powered and driven by two auxiliary unity gain buffer amplifiers 92, 94, with the connections as depicted in the diagram. The outer or second conductor 86 is surrounded on both sides by a screen and these two screens 82, 88 are connected in parallel at the input end of the cable such that the electric field between the conductor and screens remains a zero or constant.

[0091] Figures 6e and f show further embodiments in which two cables 50, 50' and four cables 50, 50', 50", 50"', respectively are configured with conductor cross-coupling as shown in the diagram. The use of parallel cables both lowers the loop inductance and the cable resistance and also forms a structure that has symmetry with respect to the way the conductors are interconnected to the balanced output power amplifier. In principle, further pairs, in order to retain symmetry of parallel cables can be added to the complex.

[0092] By way of example, it is anticipated that in a low-level signal application, the peak current demand of each unit-gain buffer will not normally exceed around 1 mA (assuming a 2 volt maximum output voltage), so standard audio grade operational amplifiers will be suitable in this application. (*circa* 20 MHz GBP, 20 V/μs slew rate, 10mA output current, unity-gain stable).

[0093] A common configuration often employed in high-end audio systems is to use multiple cables between the power amplifier and loudspeaker in order to drive for example the high-frequency and low-frequency drivers individually, a technique commonly called bi- or tri-wiring. In such a scheme the loudspeaker manufacturer separates the high-pass and low-pass crossovers and associated drive units and then makes available to the consumer separate pairs of terminals.

[0094] The extension to bi-wiring using an active cable is shown in Figure 7 where a unity-gain buffer auxiliary amplifier 52 is employed to power and drive the screens of the two active cables 54, 56. However because both cables receive the same input voltage then only the single auxiliary amplifier 52 is required. The total capacitive load presented to the buffer amplifier is increased but it is only necessary to ensure this amplifier can provide the required peak input current; otherwise there is no additional electronic complication. Although Figure 7 shows a two-way system, the same principle can be extended to systems using more drive units and crossover networks as well as balanced operation.

[0095] Figure 8 illustrates a further embodiment of the embodiment shown in Figure 2 in which the series losses are shown as two impedances $r_{sl} + j\omega L_{s1}$ and $r_{s2} + j\omega L_{s2}$ for the "hot" (or live) and "cold" conductors 6, 10 respectively and through which the load current circulates. The instantaneous voltages are sensed and the derived voltage applied to a corrective feedback loop where the sign of the feedback is defined in the diagram. In effect the loss of output voltage due to the cable is measured and feedback causes the actual output voltage of the amplifier to rise such that the voltage across the loudspeaker Z_L 26 is the voltage that would occur if cable losses were zero. The load voltage is now independent of the series cable losses.

[0096] Typically the losses in the "hot" or positive and "cold" or negative conductors 6, 10 will not necessarily be the same and hence require individual sensing, and, as loudspeaker cables are relatively long, they can be susceptible to hum and interference induction. However, such interference causes virtually identical voltage induction in each conductor whereas the two loss signals due to the circulating load current have opposite polarities. Sensing the signals in both conductors will cause the interference to be substantially cancelled and therefore not fed back into the amplifier. The sensing of the loss voltage across the conductor 6 can be more problematic as this carries the full output voltage. The sensing circuit must therefore have exemplary common-mode signal rejection and also not be given into non-linearity by high values of common-mode voltage as occur in power amplifiers.

[0097] In one arrangement a three-winding audio frequency transformer is provided. A transformer is considered ideal in this application as it offers good common-mode rejection and enables the two loss signals to be summed together while achieving a high degree of isolation.

[0098] In an alternative arrangement, shown in Figure 9, a modified feedback topology is used that does not require a transformer in order to achieve correction for loudspeaker cable losses. This method includes correction for the primary series Zobel network required at the amplifier output. In the design, two sensing conductors 58 are provided and connected to the "loudspeaker end" 24 of the cable, however, the topology is such that if these wires are not connected (i.e. a standard loudspeaker cable is employed) then the system reverts to the conventional topology. As such, in this embodiment, the cable requires a total of seven connections, five at the input and two at the output.

[0099] The problem of common-mode rejection is overcome by using a dual-feedback sensing system where the "hot" conductor 6 sensing is incorporated into the principal amplifier feedback path, while the "cold" conductor 10 uses a supplementary feedback path.

[0100] In whichever embodiment, the two remote-end sensing wires can be threaded down the centre core 60 of the cable as shown in Figure 8b and also twisted to reduce hum and interference susceptibility as well as forcing any residual induction to be symmetrically distributed between the two sensing conductors.

[0101] In one embodiment it is possible to eliminate the secondary Zobel network by the expedient of lowering the transition frequency of the nodal-transition filter (NTF).

[0102] The cable in accordance with the invention may also be used in low-level interconnect applications and it is suggested that because of the signal levels (typically ~ $2V)_{rms}$ maximum) encountered in low-level applications that the constrained peak current demanded by the cable capacitance allows just a single unity-gain operational amplifier to be used to drive the cable screen. As a result the cost overhead for a preamplifier is modest and Figure 10 shows a possible per-channel configuration for a preamplifier 62 output stage and active cable 64. The unity-gain buffer 66 is formed using an operational amplifier 68 with unity-gain series feedback. The supply to this amplifier has some ac-filtering to limit interaction with the main circuitry as the buffer has to drive a relatively high capacitive load; also a series input resistor is included to limit loading on the main amplifier circuitry although given the very high input impedance of a series-feedback amplifier this is an extremely minor effect.

[0103] In Figure 11 an alternative embodiment of the invention is shown where a dc polarizing voltage V_{pol} is superimposed on the ac output voltage of the auxiliary amplifier. In this embodiment dc polarization is achieved using a resistor-capacitor coupling network and a dc bias voltage. However, because the coupling capacitor C_p and cable shunt capacitance form a frequency independent attenuator, the coupling capacitor is selected to be greater than 10000 times the cable shunt capacitance, while resistor Rp in series with the polarizing voltage is selected to give a bandwidth that extends typically down to 1 Hz.

Claims

1. Apparatus including a cable, said cable including at least first and second conductors running along the length thereof, and wherein there is provided one or more screens located within the cable, with at least one of the screens located between the first and second conductors and wherein at least one of said screens is connected to means to provide power thereto during usage of the cable to carry signals and/or data therealong.

2. Apparatus according to claim 1 wherein the one or more screens are formed from, or include, a conductive material.

3. Apparatus according to claim 1 wherein the means to provide power is an amplifier, said amplifier typically provided within, or in connection with, apparatus to which one end of the cable is connected.

4. Apparatus according to any of the preceding claims wherein at least one of the conductors is connected to a means to supply power thereto.

5. Apparatus according to claim 4 wherein a single screen is provided and the voltage level of the power supplied to the screen and the voltage level of the power supplied to said at least one conductor are substantially the same.

6. Apparatus according to claim 4 wherein two or more screens are provided and the voltage level of the power supplied to a first screen and the voltage level of the power supplied to said one conductor are substantially the same, while the voltage level of the power supplied to a further screen is substantially the same as the voltage level of the power supplied to a further conductor.

7. Apparatus according to claim 4 wherein an amplifier is connected to at least one screen and is provided as an auxiliary amplifier to a main amplifier to which at least one conductor is connected, or the auxiliary amplifier is provided as an integral part of the main amplifier.

8. Apparatus according to claim 1 wherein the first and second conductors are arranged in a co-axial configuration along the cable and the at least one screen is located between said conductors and is annular in cross section.

9. Apparatus according to claim 1 wherein the first and second conductors each have individual insulated coaxial screens to form two compound conductors, and the two compound conductors are then twisted together.

10. A cable including an insulated screen located between at least two conductors along the length of the cable and wherein said screen is connected to a power supply during operation of the cable.

11. A cable according to claim 10 wherein the cable includes at least two screens located between said at least two conductors along the length of the cable and the other of said screens is connected to a ground connection at the input to the cable.

12. A cable according to claim 10 wherein the cable includes at least two insulated screens located between at least two conductors along the length of the cable and the other said screen is connected to a second power supply during the operation of the cable.

13. Apparatus including a cable having a plurality of conductors therealong and one or more screens located between at least two of the said conductors, said screens being provided with power from one or more auxiliary amplifiers and at least one of the conductors being provided with power from a main amplifier and wherein the voltage drop is substantially zero.

14. Apparatus including an amplifier and a cable for connection at one end to the amplifier and, at the other end to an item of apparatus to receive and/or transmit data and/ or signals via the cable, said cable including at least one screen located substantially along the length of the cable, wherein said at least one screen is connected to receive power from a power supply during use of the cable, so as to reduce the impact of any or any combination of DC resistance, loop inductance and/or shunt capacitance.

15. Apparatus according to claim 14 wherein the said at least one screen is located intermediate the first and second conductors.

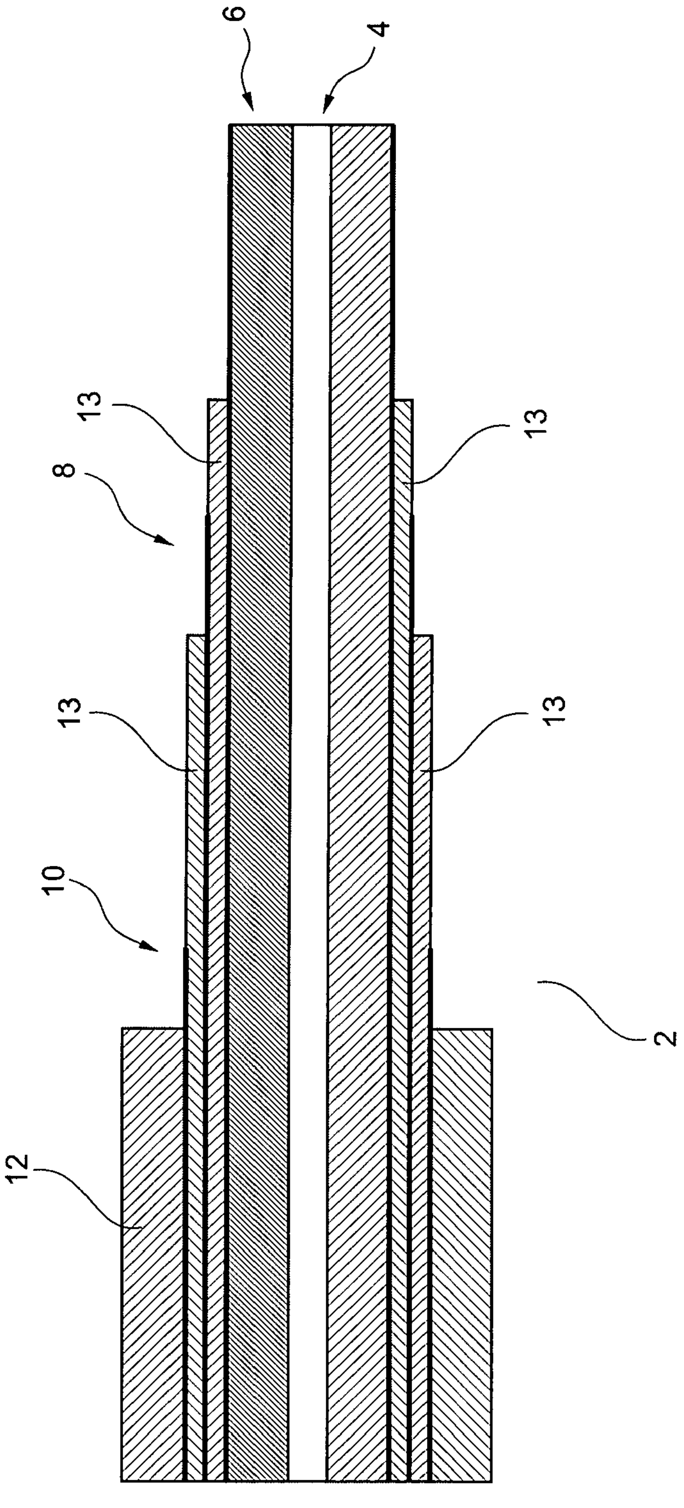

Fig. 1a

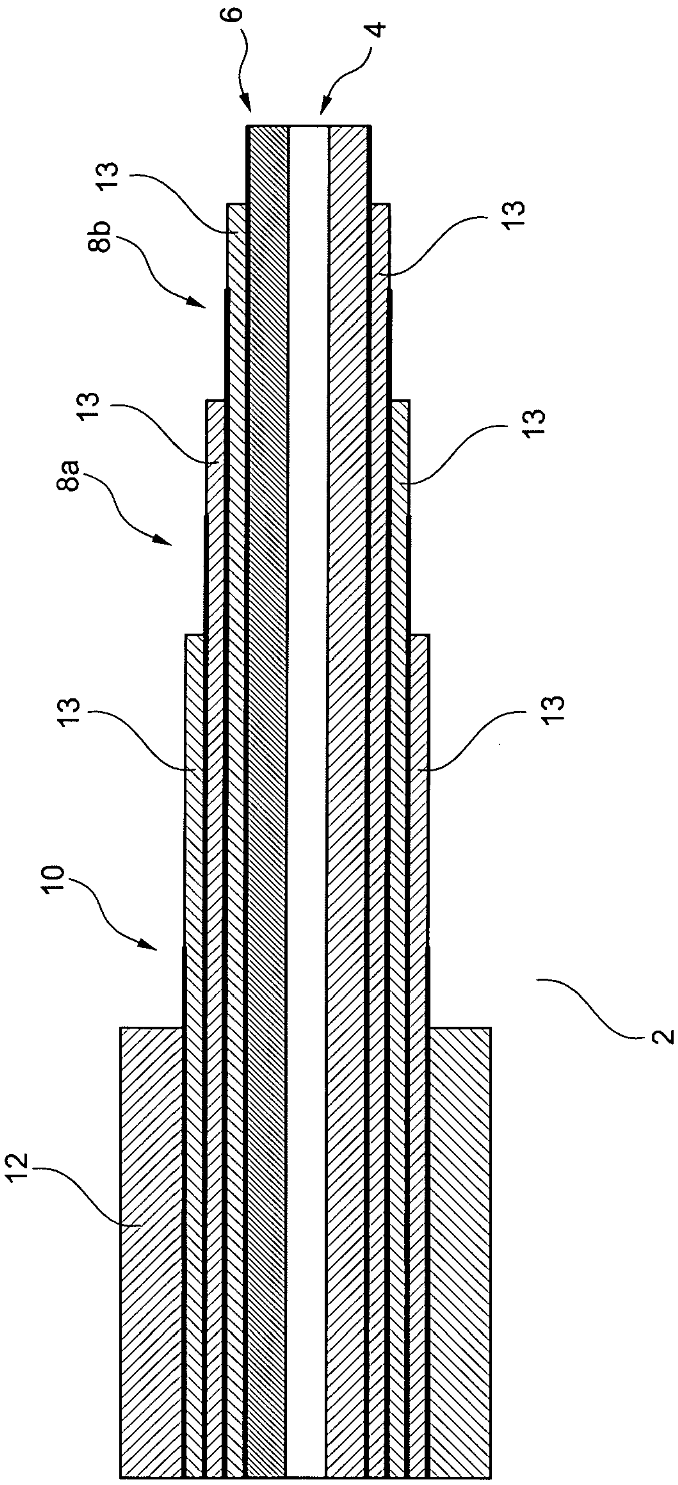

Fig. 1b

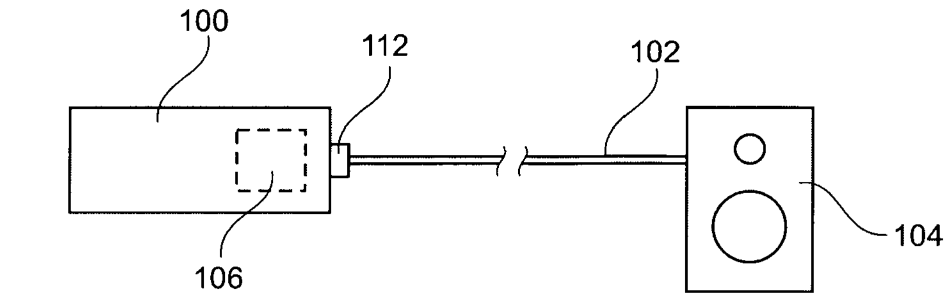

Fig. 1c

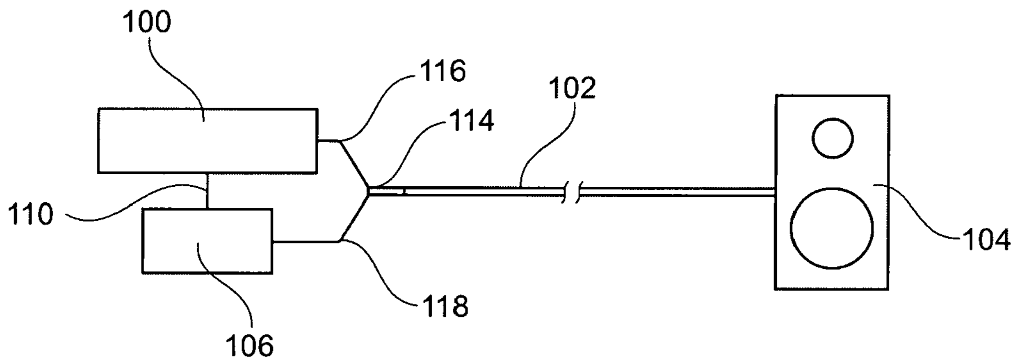

Fig. 1d

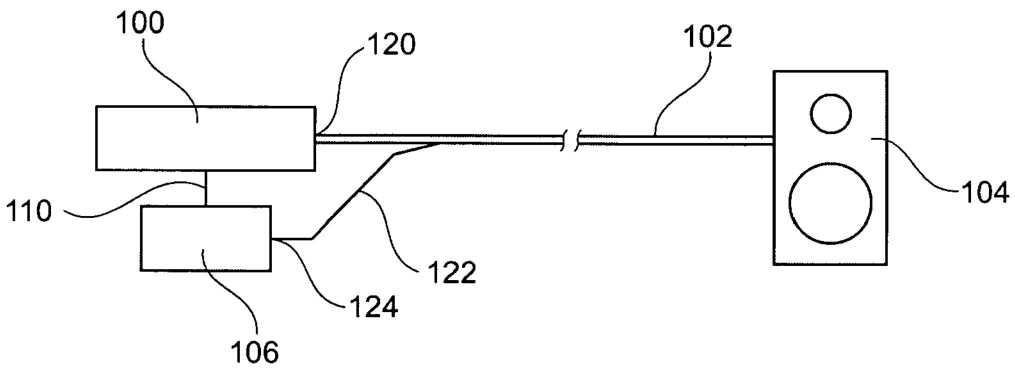

Fig. 1e

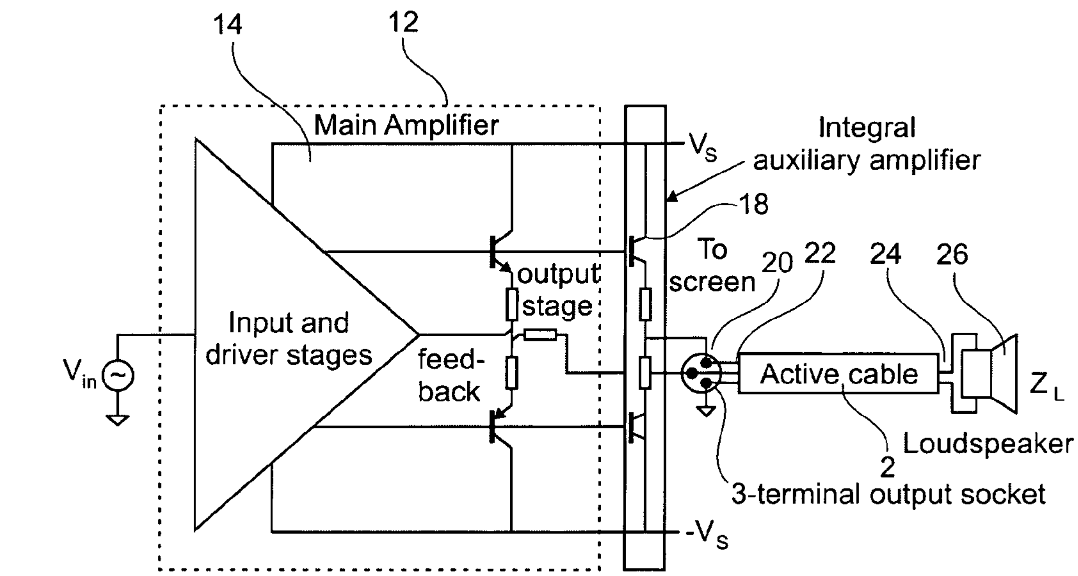

Fig. 2

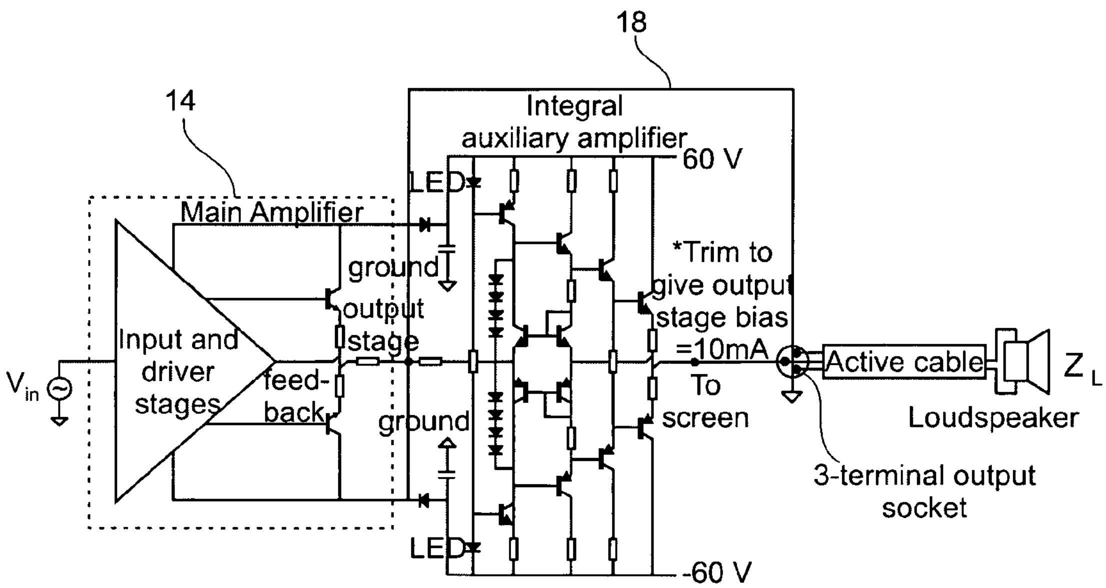

Fig. 3

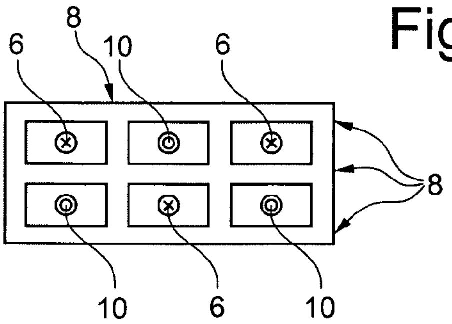

Fig. 4a

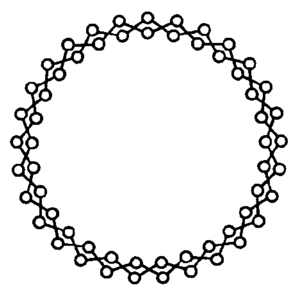

Fig. 4b

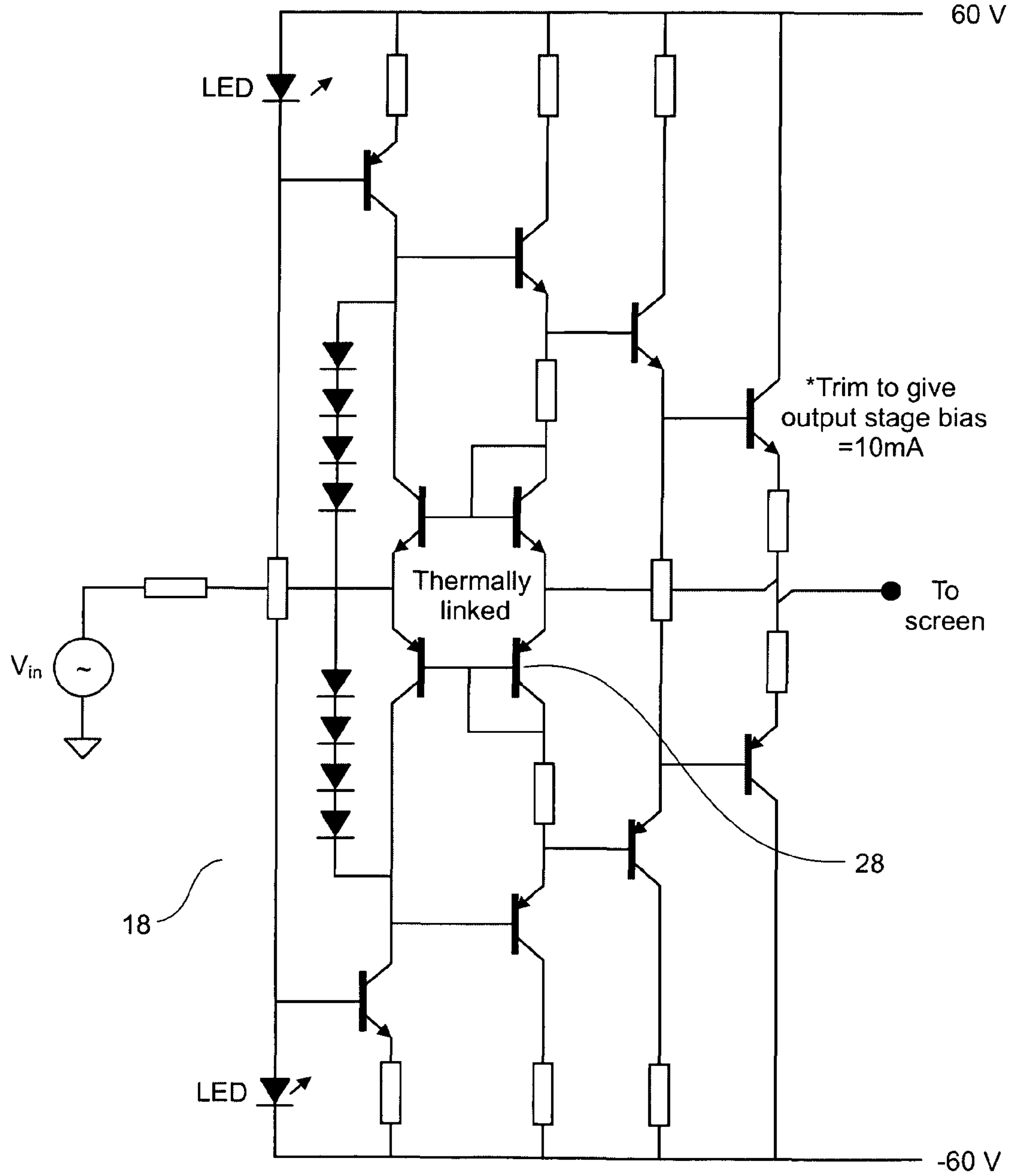
60 V
LED
*Trim to give output stage bias =10mA
Thermally linked
To screen
Vin
28
18
LED
-60 V

Fig. 5

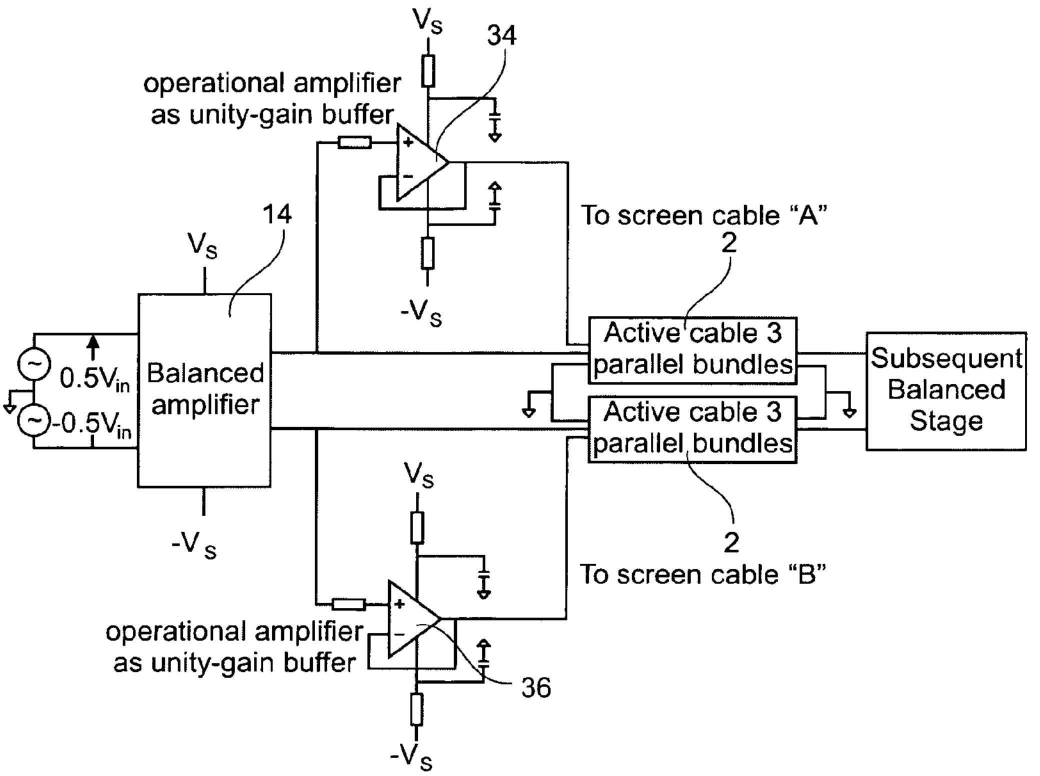
Vs
34
operational amplifier
as unity-gain buffer
+
-
14
Vs
To screen cable "A"
2
-Vs
Active cable 3
parallel bundles
0.5Vin
Balanced
amplifier
-0.5Vin
Subsequent
Balanced
Stage
Active cable 3
parallel bundles
Vs
-Vs
2
To screen cable "B"
operational amplifier
as unity-gain buffer
36
-Vs

Fig. 6a

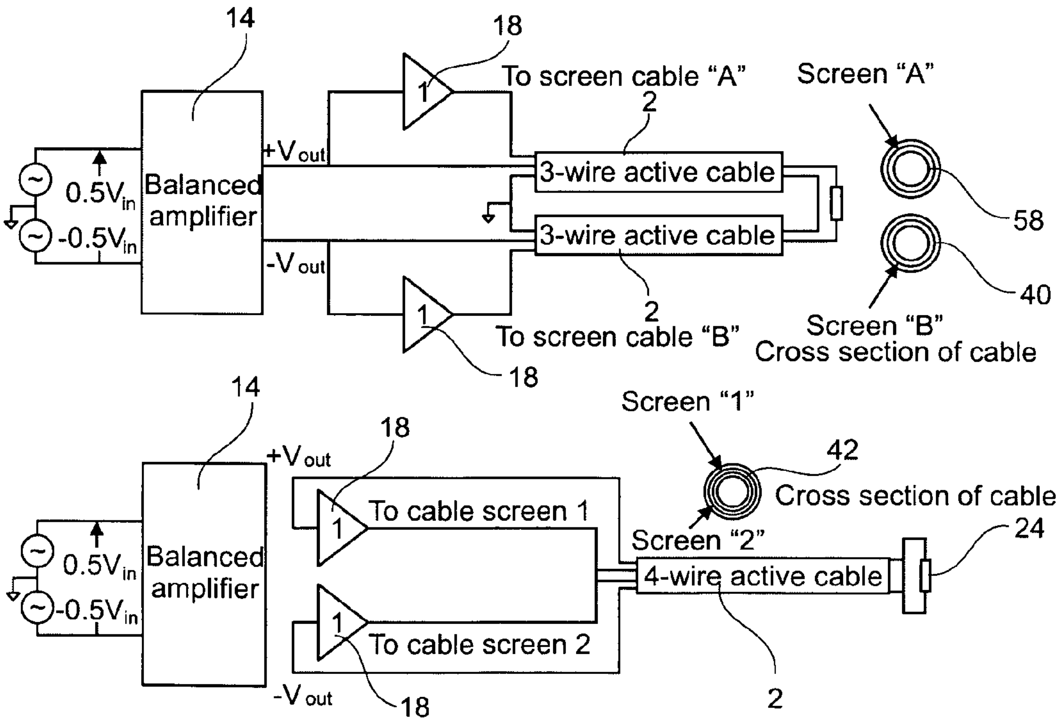
14
18
To screen cable "A"
Screen "A"
2
+Vout
3-wire active cable
0.5Vin
Balanced
amplifier
-0.5Vin
3-wire active cable
58
-Vout
1
1
2
40
To screen cable "B"
Screen "B"
Cross section of cable
18
14
Screen "1"
18
42
+Vout
Cross section of cable
To cable screen 1
24
Screen "2"
0.5Vin
Balanced
amplifier
4-wire active cable
-0.5Vin
To cable screen 2
-Vout
18
2

Fig. 6b

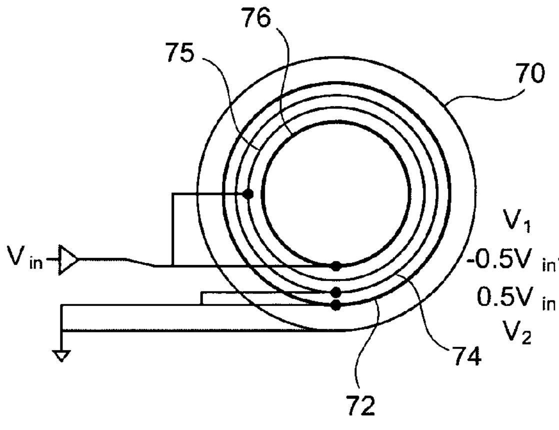

Fig. 6c

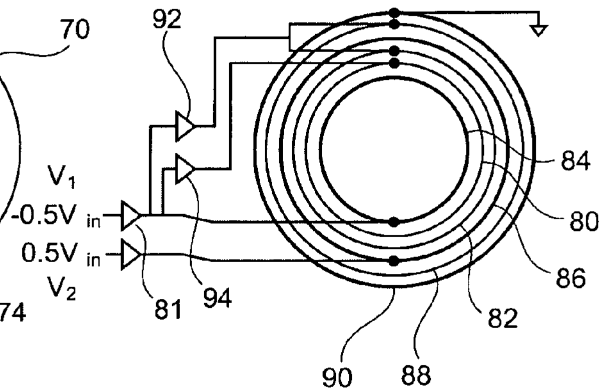

Fig. 6d

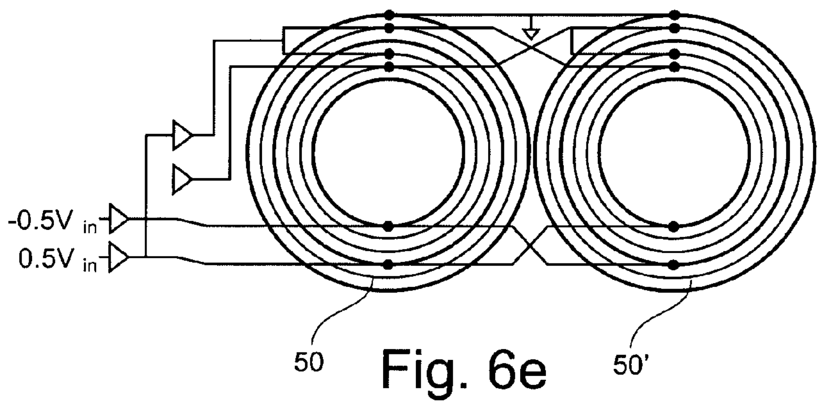

Fig. 6e

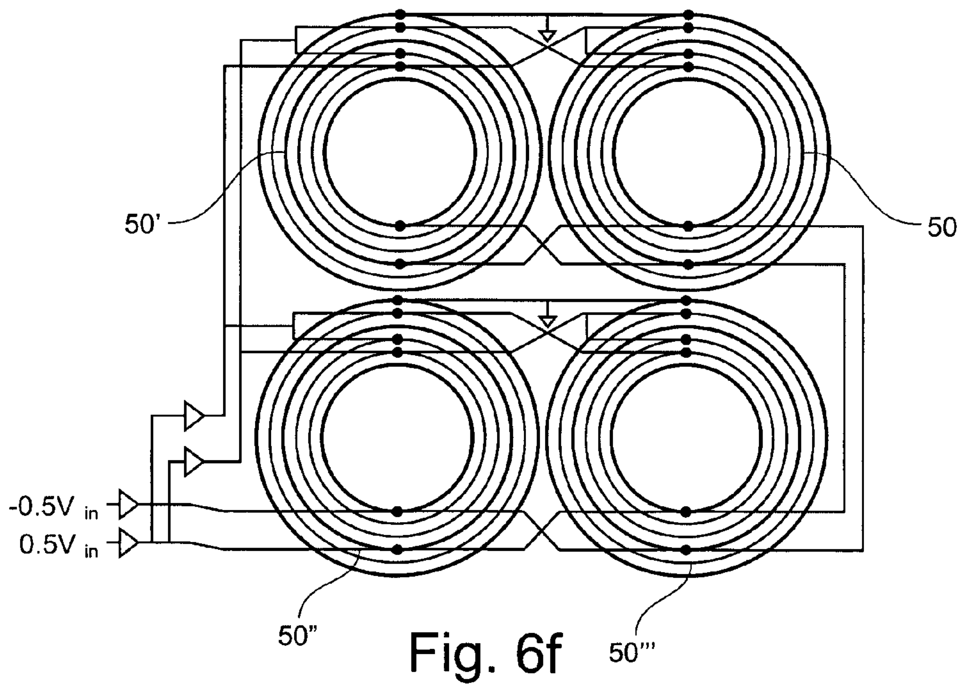

Fig. 6f

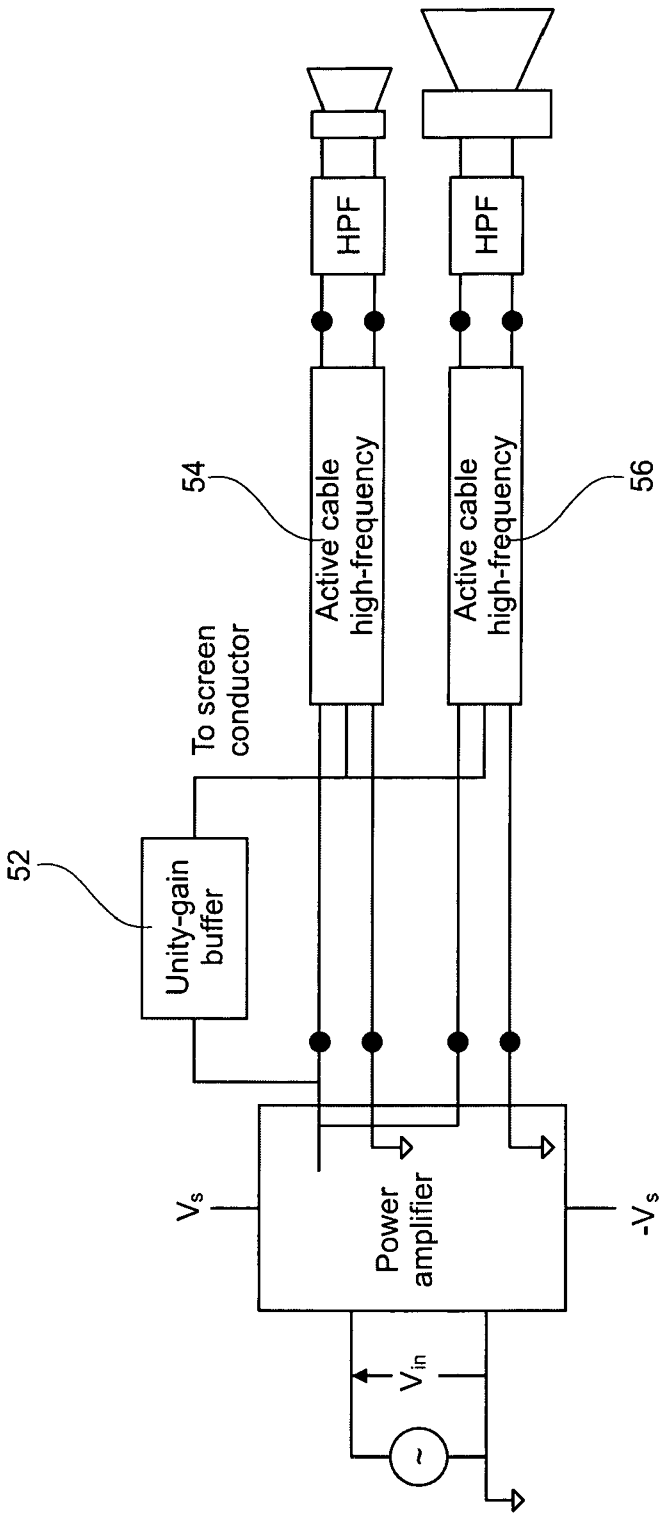
HPF
HPF
54
Active cable
high-frequency
56
Active cable
high-frequency
To screen
conductor
52
Unity-gain
buffer
V_s
Power
amplifier
$-V_s$
V_{in}
~

Fig. 7

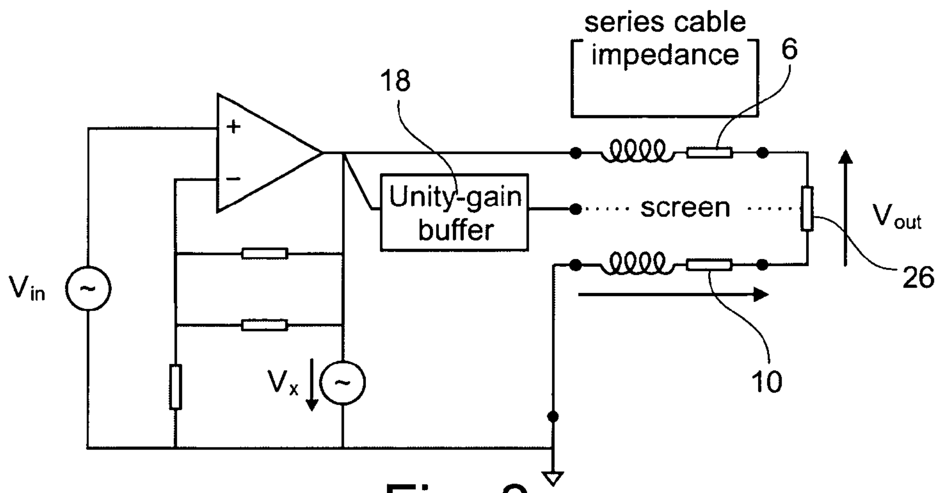

Fig. 8

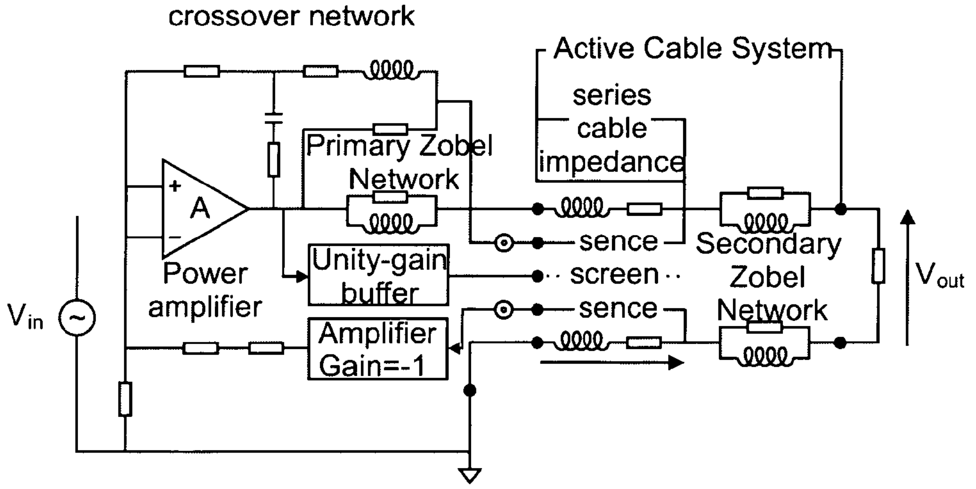

Fig. 9a

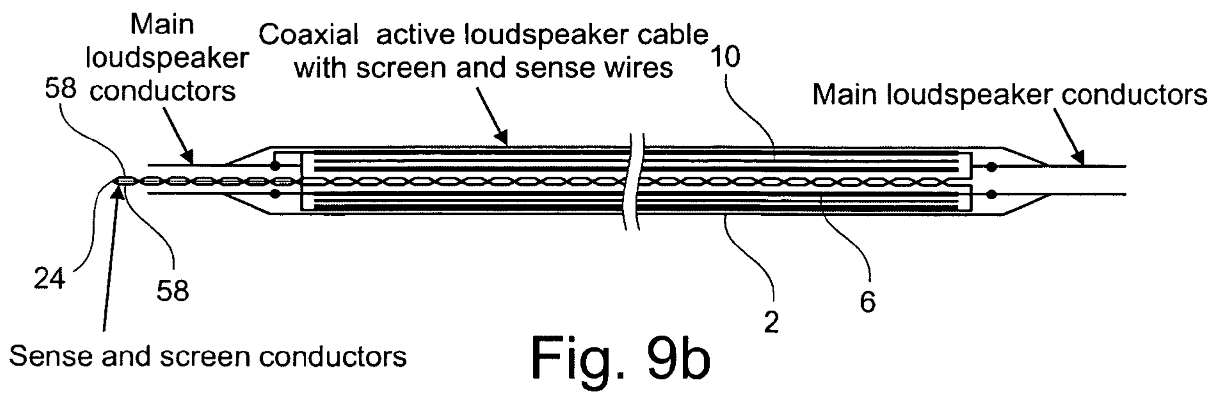

Fig. 9b

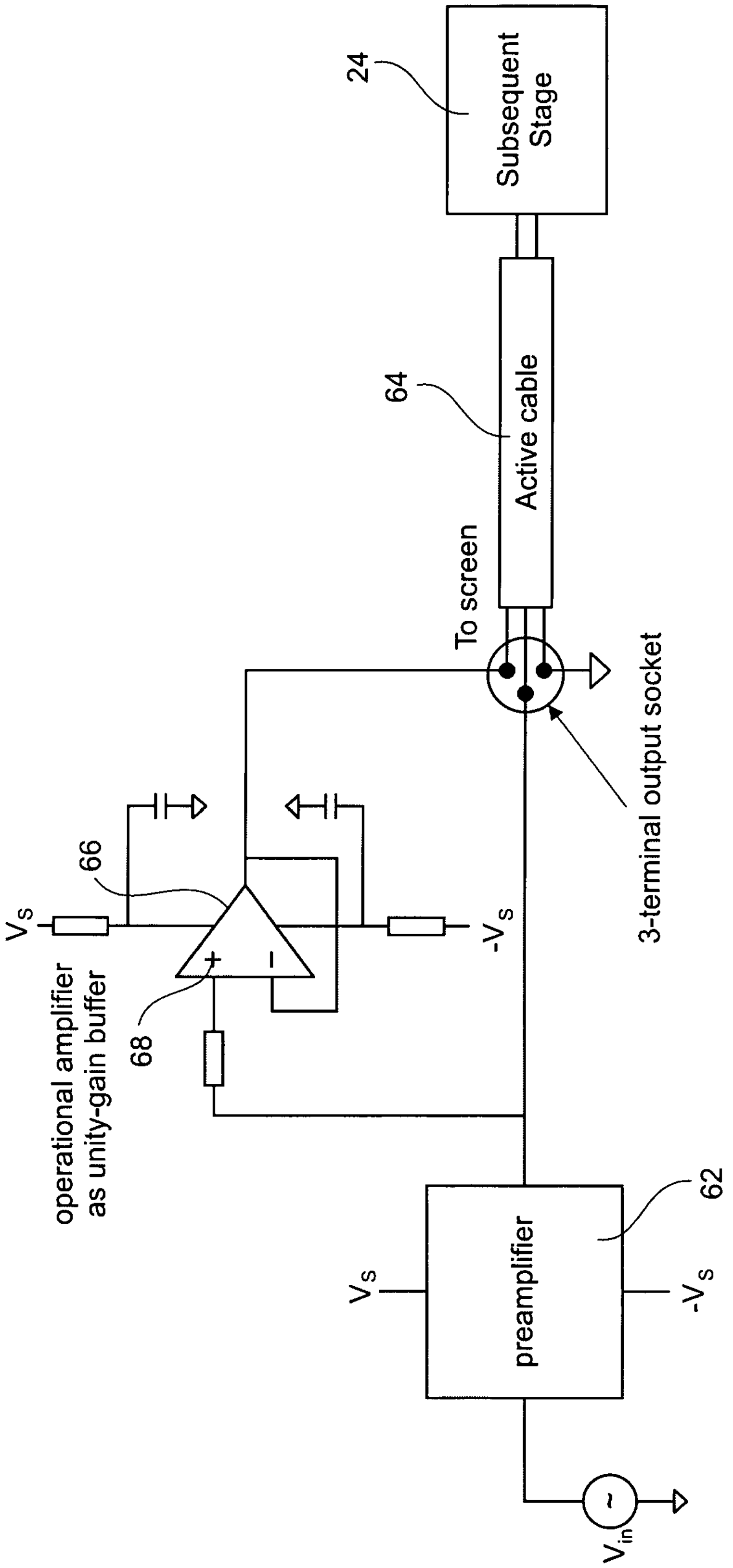
Subsequent
Stage
24
Active cable
64
To screen
3-terminal output socket
operational amplifier
as unity-gain buffer
66
68
V_S
-V_S
preamplifier
62
V_{in}

Fig. 10

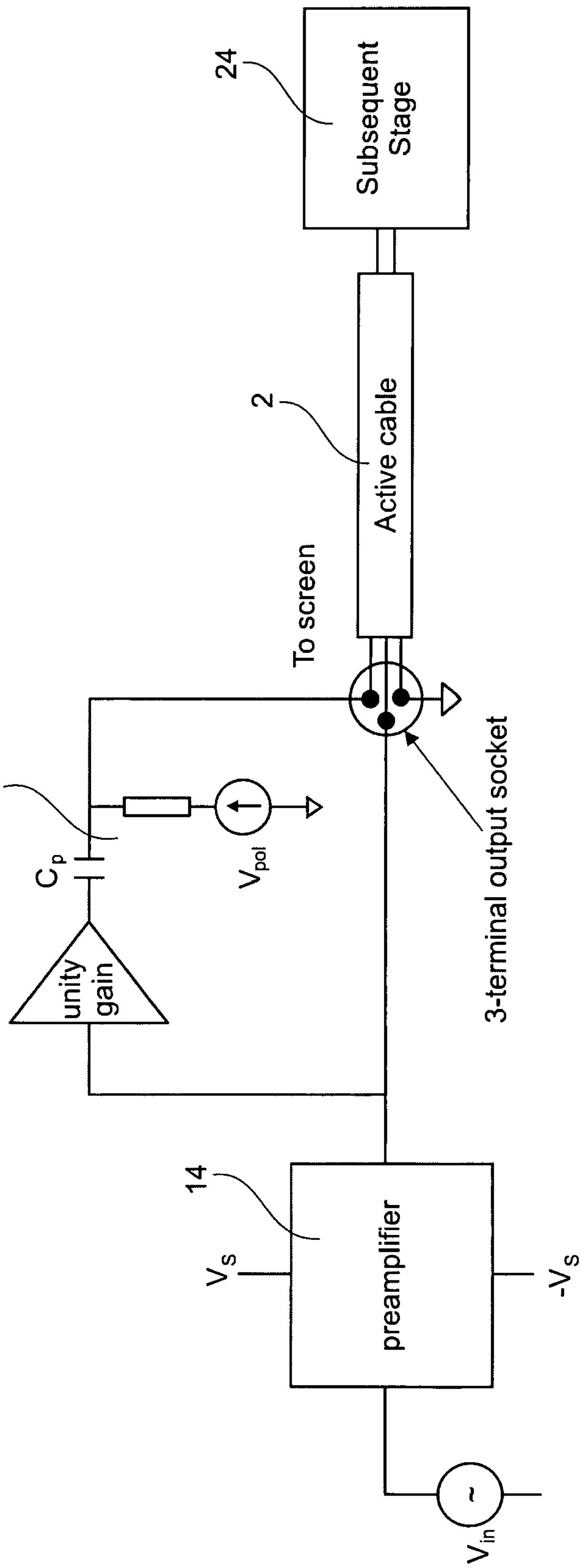
24
Subsequent Stage
2
Active cable
To screen
18
C_p
V_{pol}
unity gain
3-terminal output socket
14
preamplifier
V_S
$-V_S$
V_{in}

Fig. 11