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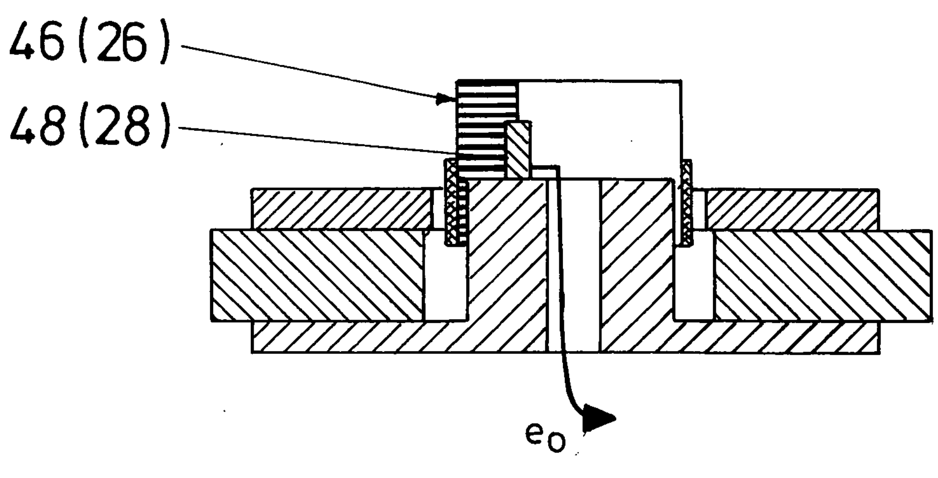
(54) **Motional feedback loudspeaker**

(57) A detection system for detecting the motion and/or position of the diaphragm or the moving-coil system of a sound system, said moving-coil system comprising a coil carrier and a coil wound about said coil carrier, said moving-coil system moving along with said diaphragm, said detection system comprising a transmitter (48) for generating light, said transmitter mounted on the non-moving part of said sound system, an optical structure (46) constituting segments for either reflecting or letting pass the light from said transmitter, said optical structure constructed on said moving-coil system, and a receiver (48) comprising at least one photosensor for detecting the light generated from said transmitter and then either let pass or reflected by said optical structure and generating electric signals accordingly, said receiver mounted on the non-moving part of said sound system.

FIG 4



EP 1 569 497 A1

Description

Field of the invention:

[0001] This invention relates to detection systems and methods for detecting the position and/or movement of loudspeakers, methods for reducing acoustic distortions in sound systems and such sound systems. More particularly, this invention relates to detection systems using optical distance, speed, and velocity measurement technologies, and to electro-dynamic sound systems that employ the motion feedback control technique to improve the sound fidelity by reducing the acoustic distortions in the lower frequency range.

Background of the invention:

[0002] It is known in the art that the conventional electro-dynamic sound system suffers from an inadequate response in the lower frequency range especially at higher signal levels and therefore the sound reproduced by the sound system is usually distorted. Main causes of this distortion are the non-linearities of the sound system resulting from its mechanical system as well as the drive system. For instance, at low frequencies, the mechanical and electrical characteristics of a sound system tend to reduce the sound level for output.

[0003] In order to improve the acoustic quality of the sound system, it is highly important to eliminate or to reduce as much as possible such distortions. Many corrective mechanisms have been developed in this regard, among which the motion feedback control technique is by far the most common. In general, an electro-dynamic sound system employing the motion feedback control detects vibration, or movement, of a vibrating system of the sound system such as its diaphragm or coil carrier, and sends this vibration back to an amplification circuit to form a negative feedback for driving the vibrating system. It is thereby possible with this type of sound system to reproduce audio signals with high fidelity.

[0004] The motion feedback control technique requires, in general, sensor signals that encode information about the current motional condition of a loudspeaker such as the position, the speed, and/or the acceleration of the diaphragm or the coil carrier. The knowledge of one or more of these values allows a correction signal to be calculated as the feedback. Then, by superimposing this correction signal onto the original input signal to the sound system, a feedback loop is completed and in turn a lower distortion achieved for the sound system.

[0005] As known to those skilled in the art, the detection of the movement and/or position of the diaphragm or the coil carrier and the generation of sensor signal(s) are accomplished through one of the following conventional means:

> acceleration receivers, for example, piezo-sensors, secondary coil systems, microphones in the vicinity of a sound system or within the housing, and distance measurement by means of reflected light intensity or laser triangulation. The calculation of the correction signal is often achieved by means of a signal processing circuitry that is implemented in the amplifier of the sound system.

[0006] US application publication US 2003/00724622A1 discloses the usage of two sensors, a position sensor and an acceleration sensor to detect the movement of the voice coil of a loud speaker and in turn to generate feedback control signals. However, these two sensors and their corresponding feedback networks are complicated electrical circuits and therefore prone to variations in environmental conditions such as acoustic venues, temperatures, and air densities in the loudspeaker.

[0007] US patent 4,573,189 to Hall proposes feedback means for a loudspeaker including a small motion sensing element, such as an accelerometer, mounted on the voice coil. This mechanism suffers from, as admitted by the inventor himself, a significant low frequency instability of the feedback loop. To try to solve this problem, US-Patent 4,727,584 proposes an improvement to the motional feedback technique by enclosing the accelerometer in an air-tight shield. This solution nevertheless results in an increased mass weight of the loudspeaker thereby effecting speaker characteristic.

[0008] Usage of a second coil system in a loudspeaker for detecting the displacement of the diaphragm is described in US patent 5,533,134 to Tokura et al. and US patent 4,609,784 to Miller. In short, the detecting transducer has its terminal voltage changed responsive to the displacement of the diaphragm or the coil carrier. Such a system is expensive and complicated to implement. Moreover, the transducer itself has limited frequency response characteristics and therefore cannot fully overcome the poor low-frequency response characteristics of the associated loudspeaker.

[0009] With the progress in applied optics, new methods for distance measurement using optical devices have been developed and are increasingly being applied to motion detection. Two well known examples of these optical distance measurement techniques are 1) reflected light intensity, based on light reflection, and 2) laser triangulation, based on diffraction, interference, and laser technology.

[0010] In the prior art, there are a number of inventions relating to the usage of optical measurement system in motion feedback sound systems. An "optical motional feedback loudspeaker" is known from the published French patent application 2296985, Japanese utility model 4215110, US patent 4,207,437, etc. Invariably, these systems comprise two elements, a light source and a detector, at least one of those elements being connected to the magnet system, and the detector supplying a voltage which substantially corresponds to the displacement of the diaphragm. These systems pose several inevitable drawbacks, for instance, the intricate implementation of optical devices constituting an acoustic obstacle for the sound being reproduced, and an increased moving weight for the sound system thereby reducing the efficiency.

[0011] It is a fact that the above mentioned motion feedback control techniques do help to reduce the loudspeaker distortions and thereby improve the sound quality. Nevertheless, they are often complicated and expensive to construct, sensitive to interferences and environmental factors, and/or pose a difficulty in reducing the mass weight as well as the size of the loudspeaker or the sound system. Furthermore, the invasive nature of these techniques precludes their use in low- to medium-priced products.

[0012] Therefore, an economical and robust detection system for sensing the motion of the sound system is highly desirable.

Summary of the invention

[0013] It is an object of this invention to provide an economical and robust detection system to detect the motion and/or position of the diaphragm and/or the moving-coil system of a loudspeaker. It is an additional object that this detection system can deliver digital signals directly to enable direct processing in a digital signal processing (DSP) circuit.

[0014] This invention improves loudspeakers and sound systems by providing an optical detection system that comprises a transmitter, that is, a light source, an optical structure for either reflecting or letting pass the light from the transmitter, and a receiver constituting at least one photo-sensor for sensing the light that is reflected or is passed by the optical structure and generating electrical signals accordingly. Said optical detection system may include an additional light conducting system for ensuring that the light from the transmitter is focused onto the optical structure as a small dot or bar. The optical structure is constructed on the moving-coil system of the sound system while the transmitter and the photo-sensor on some non-moving part thereof. This detection system works in this way: when the diaphragm and/or the coil carrier vibrates, the optical structure vibrates along; this motional change is then sensed by the photo-sensor and converted into electrical signals accordingly. Thus, the movement, the speed, the velocity, and/or the position of the diaphragm or the coil carrier can be detected and translated into motion correction signals.

[0015] The optical structure used in the detection system employs optical technologies that can measure distance, speed, and velocity in a highly economical way and facilitate digital signal encoding. In one of such technologies, called "line grid," the optical structure is made up of light-passing or absorbing and/or light-reflecting optical segments, which preferably form a certain periodical pattern. A focused beam of light originated from the transmitter is either absorbed or reflected by the segments in the pattern and, accordingly, the photo-sensor reacts to either the transmitted light or the reflected light from the optical structure. When the optical structure moves, the light reaching the photo-sensor is interrupted by the positional changes of the segments modulated with a frequency corresponding to the velocity of the optical structure. Whenever the light is interrupted, the sensor generates a signal to indicate a certain amount of movement of the optical structure. Since the optical structure is fixed on the moving coil system of the sound system, this detected movement is therefore the movement of the diaphragm or the coil carrier. While a periodical optical pattern is often a necessary feature for the optical structure in the "line grid" method, it is however not required in another optical distance/speed/velocity detection technology, called "2D-array-based," in which the optical structure can be any surface that has a certain amount of optical "roughness." In the "2D-array-based" scenario, a transmitter casts light onto the optical structure which reflects that light as a patch of image onto a multiple array of photo-sensors. The sensors, reacting to optical stimulus at a certain rate, for example, 500 pictures per second, send each image to a signal processor for analysis. The signal processor detects patterns in the images and "sees" how those patterns have moved since the previous image. Based on the change in the patterns over a sequence of images, the signal processor determines how far the optical pattern has moved in various dimensions.

[0016] The above mentioned optical distance/speed/velocity detection technologies have many advantages. Firstly, they are easy and inexpensive to implement. Secondly, they are robust due to their immunity to the variation in the environmental conditions. Last but not least, they provide possibilities to output measurement signals in the digital form.

[0017] It is another object of this invention to incorporate such a detection system into a sound system so as to utilize the signals output from the detection system as the basis for generating a motion correction signal for the purpose of feedback control. Integrating the detection system described above and signal processing technology into a sound system, a motion feedback control sound system can be constructed. This sound system comprises

a diaphragm for producing the acoustic wave,

a driving system for driving this diaphragm in response to an input signal, with this driving system comprising a moving-coil system which further comprises a coil carrier mounted on the diaphragm and a voice coil wound about the coil carrier and connected to receive the input signal, and a magnet assembly for producing a magnetic field for generating the driving power driving the diaphragm along with the moving-coil system,

an optical detection system as mentioned above for detecting the motion, speed, and/or position of the diaphragm or the moving-coil system, and

a signal processing circuitry for at least interconnecting the driving system and the detection system, processing the electric signals from the detection system into a motion correction signal, mixing such motion correction signal with the input signal, and feeding the resultant mixed signal to the driving system. With such a construction, the electrical signals output from the detection system are processed into a motion correction signal which is to be fed-back into the sound system.

[0018] Corresponding to the detection system and the sound system mentioned above, methods are provided to detect the motion, speed, velocity, and/or position of the diaphragm or the moving-coil system of a sound system and how to use this detection system in the sound system to achieve a lower acoustic distortion.

Brief description of the drawings

[0019] The invention can be better understood with reference to the following drawings and descriptions. The components in the figures are not necessarily to scale, instead emphasis being placed upon illustrating the principles of the invention. Moreover, in the figures, like reference numerals designate corresponding parts. In the drawings:

Fig. 1 is a schematic diagram of an electro-dynamic loudspeaker according to the present invention;

Fig. 2 is a cross-section view of the driving means of the loudspeaker;

Fig. 3 is a schematic diagram of the detection system according to the present invention;

Fig. 4 is a cross-section view of the driving system with the detection system mounted on it;

Fig. 5 illustrates the optical structure, a set of periodical line structures;

Fig. 6 illustrates another optical structure, two identical sets of periodical line structures positioned in parallel with a predefined phase shift;

Fig. 7 illustrates yet another optical structure which is a plurality of sets of periodical line structures with a discretization of n bits;

Fig. 8 illustrates yet another optical structure which is a surface of certain optical roughness;

Fig. 9 illustrates a detection system using the "two sets" optical structure and two photo sensors.

Fig. 10 is the block diagram of a possible signal processing circuitry of the sound system in accordance with the present invention.

Detailed description

[0020] Referring to Figure 1, the complete sound system 10 in the present invention comprises, among other parts, three major components: a driving system 16, a detection system 18, and a signal processing circuitry 20. The motion feedback control process of the sound system works as follows: initially, the input terminal 12 receives an input signal e_i representing the sound signal to be reproduced; next, e_i is applied to a mixing point 14, which mixes the signals coming in and outputs signal e_c to drive the driving system 16 of the sound system and thereby cause the diaphragm and the coil carrier to vibrate; then, the detection system 18 detects the motion of the diaphragm or the coil carrier and produces motion signals e_o accordingly; after that, e_o is input to the signal processing circuitry 20 where e_o is processed into a motion correction signal e_f; finally, e_f is fed back to the mixing point 14 to be mixed with the input drive signal e_i to form the corrected input signal e_c.

[0021] Related mechanical configuration of the driving system of the sound system is illustrated in Figure 2. It can be seen that the driving system comprises a moving-coil system and a magnet assembly. The moving-coil system includes a voice-coil 26 wound about a cylindrical coil carrier 24 which is mounted on the base 22 of the diaphragm (not otherwise shown). Since connected together, the diaphragm and the coil carrier move along with each other. The magnet assembly is to produce a magnetic field for generating the driving power to drive the based 22 of the diaphragm. An example of the magnet assembly is a ring magnet 30 with pole pieces 32 and 33. A conventional spider 28 holds the voice-coil in proper alignment as it moves in the air gap 34 of the magnet. All the above elements are conventional in the art.

[0022] Figures 3 and 4 concern the details of the detection system of the present invention. Figure 3 schematically depicts the constituting elements of the detection system while Figure 4 shows how this system can be incorporated into a sound system.

[0023] Shown in Figure 3, the detection system 18 comprises essentially three elements: a transmitter 35 as a light source, an optical structure 36 made up of light-reflecting and/or light-passing/absorbing segments, and a receiver constituting at least one photosensor 37. The basic principle of the optical detecting is as follows: the light generated from the transmitter 35 reaches the optical structure 36 and is either reflected back or let pass; depending on the relative positions of these three elements the photo-sensor 37 reacts to either the reflected light from the optical structure 36 or the transmitted light passing through the optical structure, 36 and in turn transforms this optical stimulus into electrical signals. The relative movement of the optical structure against the transmitter and photo-sensor creates moving optical stimulus for the photo-sensor which consequently generates changing electrical signals accordingly. These electrical signals this encode within themselves the movement and/or position information of the optical structure. An example of the changing electrical signal is a square wave shown in Figure 3, whereas the "high," or "1," in the square wave corresponds to an occurrence of the light from the optical structure hitting the photo-sensor, while the "low," or "0," corresponds to a situation where there is no light reaching the photo-sensor, or vice versa. This binary encoding leads to the possibility of generating digital signals to convey the movement, speed, acceleration, and/or position information of the optical structure.

[0024] An important consideration with the use of light in this detection system is that the light from the transmitter should be preferably focused onto the optical structure so that only a small dot or bar is observed on the structure. A laser diode may be used as the transmitter because a laser diode generally emits a focused beam of light. Still, to guarantee a focused light beam, certain light conducting mechanism may be used along the path from the transmitter to the optical structure. Thus, in some case, a fourth element, a light conducting construction, such as fiber optics or a lens system 38, is included in the detection system.

[0025] Figure 4 shows that how this optical detection system may be incorporated into a sound system. The optical structure 46 is constructed on the moving-coil system of the sound system/loudspeaker, such as on the lateral surface of the coil carrier; the transmitter and the photo-sensor, together labeled as 48, are constructed on some nonmoving part of the sound system, such as inside the coil carrier. Thus, when the diaphragm or the coil carrier vibrates, the optical structure moves along while the transmitter and the photo-sensor remain stationary. As a result, the movement of the optical structure is the movement of the diaphragm and the coil carrier. This movement is detected by the photo-sensor and an electrical signal is generated accordingly. Since the frequency of the electrical signal corresponds to the velocity of the movement, a velocity signal is therefore obtainable. Moreover, integrating velocity over time gives the distance that the diaphragm or coil carrier has traveled and differentiation gives the acceleration (of the diaphragm or the coil carrier) which corresponds to the generated sound pressure. Thus, the position of the diaphragm or coil carrier is also obtained.

[0026] Various options exist for the elements of the detection system 18. For instance, being small, inexpensive, and able to generate focused light beams, diodes such as laser diodes and light emitting diodes (LEDs) are preferred choices for the transmitter although any other light source can work as well. Examples of the light conducting mechanism are fiber optics, lenses, etc. Instances of the optical structure will be discussed in the detail description of Figures 5-7. The photo-sensors may be Charge Coupled Devices (CCD), photo-diodes, photo-transistors, Complementary Metal Oxide Semiconductor (CMOS) sensors, and many more. The number of the photo-sensors can vary as well: a signal photo-sensor, a pair of photo-sensors, a line array of photos, and a multiple array of photo-sensors. As to the positions of these elements, the arrangement of having the optical structure 46 constructed on the moving coil system while both the transmitter and the photo-sensor mounted on some non-moving part of the sound system is sufficient to create an observable relative movement between the optical structure and the transmitter and photo-sensor. Nevertheless, as discussed later, a preferred construction site for the optical structure is the lateral surface of the cylindrical coil carrier, especially the inner lateral surface. In this case, when reflected light from the optical structure is used as the optical stimulus for the photo-sensor, both the transmitter and the photo-sensor may (preferably) reside inside the coil carrier. Alternatively, when transmitted light is used, one of the transmitter and the photo-sensor should be positioned inside the coil carrier and the other one outside.

[0027] The fundamental requirement for the optical structure used in the detection system is that the structure is made of segments that are either light-reflecting or light-passing/absorbing. Considering the various factors for manufacturing the optical structure, such as the shapes and dimensions of either the segments or the entire optical structure, the pattern that the segments can form, the material used for either the optical structure as a whole or for the individual segments, etc., the optical structure may be constructed in a large number of ways. Three optical structures are presented in Figures 5-7 as examples of the "line grid" optical detection system proposed in the present invention. In their respective descriptions, emphasis are placed on the pattern that the segments form, the mechanical construction of the optical structure on the sound system, and the motion/position information that such patterns can convey.

[0028] Referring to Figure 5, an optical structure 48 is made of a set of line segments which are either light-reflective (shown as dark lings 52 in the figure) or light-passing/absorbing (shown as light lines 54 in the figure). The lines are of equal thickness and, therefore, form a wave with the period (P) comprising a pair of dark and light lines. In order to crate easy-to-observe changes in the relative movement between the optical structure and the photo-sensor, this wave of periodical lines is formed to propagate in parallel to the direction of the movement of the diaphragm or the coil carrier. Thus, it is ideal to construct this line wave on the lateral surface of the coil carrier and in such a way that it propagates in parallel to the axis of the symmetry of the coil carrier.

[0029] As regards to the actual construction of this wave of periodical line structures, many materials and mechanisms can be used, among which, for example, the following solutions are preferred:

The wave of periodical line structures may be formed by making periodical groves into the lateral surface of the coil carrier. The groves may be made by means of a tool such as a file, a rasp, or a brush. The lateral surface can either be in the inner or the outer lateral surface of the coil carrier;

The wave of periodical line structures may be formed by attaching a metallic layer onto a plastic foil, printing periodical lines on the metallic layer in the way similar to the manufacturing of compact discs (CD), and then attaching the plastic foil firmly to the lateral surface of the coil carrier. Again, this lateral surface can be either the inner or the outer lateral surface of the coil carrier;

The wave of periodical line structures may be formed by the inherent periodical structure of the voice-coil 56 wound about the coil carrier;

The wave of periodical line structures can be formed by making periodical vents on the lateral surface of the coil carrier.

[0030] An optical structure made of a single set of periodical lines as described above allows the speed of the movement to be detected. With periodical light-reflective or light-passing/absorbing lines, each time the optical structure moves along with the diaphragm or the coil carrier, the beam of light from the transmitter is interrupted by these lines and this interruption is sensed by the photo-sensor. Since these lines are equally thick, the number of interruptions per unit time therefore corresponds to the speed of the movement of the optical structure, or said in another way, the speed of the movement of the diaphragm or the coil carrier. Thus, the electrical signals generated by the photo-sensor are encoded with the information of the speed of the diaphragm or the coil carrier. Integrating this speed over time gives the distance that the diaphragm or coil carrier has traveled and differentiation gives the acceleration (of the diaphragm or the coil carrier) which corresponds to the generated sound pressure. Thus, the speed, the acceleration, and/or the position of the diaphragm or coil carrier is also obtained.

[0031] Another optical structure made of line segments that are either light-reflective or light-passing/absorbing is shown in Figure 6. This optical structure comprises two identical sets of periodical line structures positioned in parallel with a predefined phase shift in their wavefronts. The phase shift is preferred to be a quarter of the wave period. The use of such two sets of line segments along with a pair of photo-sensor enables not only the speed but also the direction of the movement of the optical structure to be detected. Thus, the electrical signals generated by the photo-sensors are encoded with the information of the speed and the direction of the movement of diaphragm or the coil carrier. The actual construction of the lines may be achieved in various ways including making periodical grooves into the lateral surface of the coil carrier; attaching a metallic layer onto a plastic foil, printing periodical lines on the metallic layer and then attaching the plastic foil firmly onto the lateral surface o the coil carrier; or many others. Similarly, integrating the speed over time gives the distance that the diaphragm or coil carrier has traveled and the time derivative is the acceleration. Thus, the position of the diaphragm or coil carrier is also obtained.

[0032] Referring to Figure 7, yet another optical structure 48 is shown to be made of light-reflective and light-passing/absorbing line segments, similar to those in the previous two optical structures. These line segments forms a plurality of sets of periodical line structures positioned in parallel with a discretization of n bits. Particularly in Figure 7, there are four sets of periodical line structures with a discretization of four bits. This optical structure may be constructed in the same ways as those described in Figure 6. Therefore, the sets of line structures are preferably attached to the lateral surface of the coil carrier. The set that is attached directly on top the lateral surface is labeled "layer 1" 71 and has a period of P; the set that is attached on top of "layer 1" is called "layer 2" 72 and has a period of P/2; this continues and the "layer 3" set has a period of P/4 and the "layer 4" set P/8. This arrangement of the four sets, together with a line array of four photo-sensors as the receiver facilitates the binary encoding of four bits (as the "0101" shown in the figure), a mechanism that makes possible the detection of the precise position of the diaphragm or the coil carrier. Thus, the electrical signals generated by the line array of four photo-sensors are encoded with the position information of the diaphragm or the coil carrier.

[0033] While the optical structures described above fall into the "line grid" category of the optical detection, an optical structure using the other category, "2D-array-based," is illustrated in Figure 8. Different from the "line grid," the "2D-array-based" technology does not require any periodical pattern to be separately constructed; instead, any surface can be used as the optical structure as long as the surface has a certain degree of optical roughness. In the present invention, a preferred surface is the lateral surface if the coil carrier. Another difference from the "line grid" method is that, in the "2D-array-based" scenario, the light illuminating the optical structure does not have to be focused into a small dot or bar. For example, the lens system projects the line image onto the detector which can react to the changes in this image. With the cooperation of a diode as the transmitter and a multiple photo-sensor array, such as a CCD chip, a matrix array of CMOS sensors, a matrix array of mixed CCD/CMOS sensors, etc. as the receiver, this surface enables a more comprehensive determination of the movement and/or position of the diaphragm or the coil carrier. For instance, movement vectors, positional changes dx and dy, and so on, can all be detected. Reference is made to numerous publications regarding optical mouse technology, such as the article "How do optical mice work?" retrieved from the "Howstuffworks" website. (http://computer.howstuffworks.com/question631.htm)

[0034] The optical structures having been discussed, Figure 9 illustrates on specific details how one of these optical structures, the "two sets" one as shown in Figure 6, may be used to accomplish the motion detection. In this example, the optical structure in use comprises two identical sets of periodical line structures 86'and 86" positioned in parallel with a phase shift of a quarter of the wave period. The optical structure is attached to the inner lateral surface of the coil carrier, with the sets of line structures propagating in the direction parallel to the axis of symmetry of the coil carrier. The transmitter 82 is a laser diode, the receiver a pair of photo-sensors 88'and 88''. Both the laser diode and the photo-sensor reside inside the coil carrier. The laser diode generates a focused beam of light onto the optical structure. The light reflecting lines of the optical structure reflect this incoming light while the light-passing/absorbing ones let it pass. The reflected light from the two sets of line structures 86'and 86" reach the photo-sensors 88'and 88" respectively. The two photo-sensors react to this optical stimulus and generate binary electrical signals as the two square waves shown in this figure. These binary signals allow the speed as well as the direction of the movement of the diaphragm or the coil carrier to be calculated. Integrating the speed over time gives the distance that the diaphragm or coil carrier has traveled and the time derivative is the acceleration. Thus, the position of the diaphragm or coil carrier is also obtained.

[0035] Finally, Figure 10 is the block diagram of a possible analogue signal processing circuitry of the sound system using an optical structure made up of "two sets" of line structures as described in Figure 8. As shown, this signal processing circuitry interconnects the driving system and the detection system of the loudspeaker and processes the signal s(t) (encoded with the speed and direction information of the movement of the diaphragm or the coil carrier) from the detection system into a motion correction signal $e_c(t)$. The entire process takes a number of steps: First, upon receiving s(t) from the detection system, frequency/voltage conversion (frequency corresponds to velocity) and phase detection are carried out to get the velocity signal v(t). Second, v(t) is taken time derivative to generate the acceleration signal a (t). Next, a(t) is compared with the original input signal $e_i(t)$ in order to determine the difference therebetween. Then, this difference, $\Delta e(t)$, is applied to the mixer 94 which can be, for example, a multiplicator or an adder, and is mixed with the original input signal $e_i(t)$ to result in a corrected input signal $e_c(t)$. Finally, $e_c(t)$ is fed to the driving system of the sound system. This analogue signal processing circuitry may also be realized in digital technology.

[0036] Although the preferred embodiments of this invention have been described hereinabove in detail, it is desired to emphasize that this has been for the purpose of illustrating the invention and should not be considered as necessarily limitative of the invention, it being understood that many modifications and variations can be made by those skilled in the art while still practicing the invention claimed herein.

Claims

1. A detection system for detecting the motion and/or position of the diaphragm or the moving-coil system of a sound system, said moving-coil system comprising a coil carrier and a coil wound about said coil carrier, said moving-coil system moving along with said diaphragm, said detection system comprising

   a transmitter for generating light, said transmitter mounted on the non-moving part of said sound system,

   an optical structure constituting segments for either reflecting or letting pass the light from said transmitter, said optical structure constructed on said moving-coil system, and

   a receiver comprising at least one photo-sensor for detecting the light generated from said transmitter and then either let pass or reflected by said optical structure and generating electric signals accordingly, said receiver mounted on the non-moving part of said sound system.

2. The detection system as in claim 1 further comprising a light conducting system for conducting the light generated from said transmitter onto said optical structure.

3. The detection system as in claim 2, wherein said light conducting system focuses said light generated from said transmitter onto said optical structure such that said light reaching said optical structure as a focused dot or bar.

4. The detection system as in claim 2, wherein said light conducting system is a lens system.

5. The detection system as in claim 2, wherein said light conducting system is fiber optics.

6. The detection system as in one of the claims 1-5, wherein said transmitter is a diode.

7. The detection system as in one of the claims 1-6, wherein said at least one photo-sensor is at least one photo diode.

8. The detection system as in one of the claims 1-6, wherein said at least one photo-sensor is at least one photo transistor.

9. The detection system as in one of the claims 1-6, wherein said at least one photo-sensor is at least one Complementary Metal Oxide Semiconductor sensor.

10. The detection system as in one of the claims 1-6, wherein said at least one photo-sensor is a Charge Coupled Device.

11. The detection system as in one of the claims 1-10, wherein at least one of said transmitter and said receiver resides inside said coil carrier.

12. The detection system as in one of the claims 1-11, wherein said segments of said optical structure are line structures, said line structures being either light-reflective or light-passing or absorbing.

13. The detection system as in claim 12, wherein said optical structure is formed by at least one set of periodical line structures, each period of said set constituting a pair of light-reflective and light-passing or absorbing line structures.

14. The detection system as in claim 13, wherein said at least one set of periodical line structures propagates in the direction parallel to the axis of symmetry of said coil carrier.

15. The detection system as in claim 14, wherein said light-reflective and light-passing or absorbing line structures are of the same thickness.

16. The detection system as in claim 14, wherein said at least one set of periodical line structures are formed by making periodical grooves into the lateral surface of said coil carrier.

17. The detection system as in claim 16, wherein said periodical grooves are made into the inner lateral surface of said coil carrier.

18. The detection system as in claim 16, wherein said periodical grooves are made into the outer lateral surface of said coil carrier.

19. The detection system as in claim 14, wherein said at least one set of periodical line structures are formed by attaching a metallic layer onto a plastic foil, printing periodical light-reflective and light-passing or absorbing lines on said metallic layer, and then attaching said plastic foil firmly to the lateral surface of said coil carrier.

20. The detection system as in claim 19, wherein said plastic foil is firmly attached to the inner lateral surface of said coil carrier.

21. The detection system as in claim 19, wherein said plastic foil is firmly attached to the outer lateral surface of said coil carrier.

22. The detection system as in claim 14, wherein said at least one set of periodical line structures is one set of periodical line structures, said one set of periodical line structures formed by the inherent periodical structure of said coil wound about said coil-carrier.

23. The detection system as in claim 14, wherein said at least one set of periodical line structures is one set of periodical line structures, said one set of periodical line structures formed by making periodical vents on the lateral surface of said coil carrier.

24. The detection system as in one of the claims 14-21, wherein said at least one set of periodical line structures are two identical sets of periodical line structures positioned in parallel with a predefined phase shift in their wavefronts.

25. The detection system in claim 24, wherein said predefined phase shift is a quarter of the period of said two identical sets of periodical line structures.

26. The detection system as in claim 24 or 25, wherein said receiver comprises two photo-sensors.

27. The detection system as in claims 14 to 21, wherein said at least one set of periodical line structures are n sets of periodical line structures with a discretization of n bits, wherein n is greater than 2.

28. The detection system as in claim 27, wherein said receiver comprises a line array of n photo-sensors, wherein n is greater than 2.

29. The detection system as in claim 1 or 2, wherein said optical structure is a surface of said moving-coil system of said sound system.

30. The detection system as in claim 29, wherein said surface is the lateral surface of said coil carrier.

31. A sound system using said detection system as in one of the preceding claims, comprising

a diaphragm for producing the acoustic wave,

a driving system for driving said diaphragm in accordance with an input signal, said driving system comprising a moving-coil system which further comprises

a coil carrier mounted on said diaphragm and a voice coil wound about said coil carrier and connected to receive said input signal, and a magnet assembly for producing a magnetic field for generating the driving power driving said diaphragm along with said moving-coil system,

a detection system as in one of the preceding claims, for detecting the motion and/or position of said diaphragm or said moving-coil system, and

a signal processing circuitry interconnecting said driving system and said detection system and processing said electric signal from said detection system into a motion correction signal, mixing said motion correction signal with said input signal, and feeding the resultant mixed signal to said driving system.

32. A sound system as in claim 31, wherein said signal processing circuitry comprises

means for converting a frequency signal into a voltage signal,

means for detecting the phase of said voltage signal,

means for taking the time derivative of said voltage signal, and

means for comparing said time derivative of said voltage signal and said input signal to said driving system of said sound system and generating a signal indicating the difference therebetween, said difference signal being said motion correction signal.

33. A method for detecting the motion and/or position of the diaphragm or the moving-coil system of a sound system of the moving-coil type, said method comprising the steps:

generating light, by means of a transmitter mounted on the non-moving part of said sound system,

reflecting and/or letting pass, by means of an optical structure constructed on said moving-coil system, the light generated by said transmitter,

sensing the light reflected and/or let pass by said optical structure, by means of at least one photo-sensor, and generating electrical signals accordingly, and

calculating, by means of a signal processing circuitry, values regarding the motion and/or position of said diaphragm or said moving-coil system, based on said electrical signals from said at least one photo-sensor, and generating motion/position signals accordingly.

34. The method as in claim 33 comprising an additional step between said light-generating step and said light-reflecting/light-passing step, for focusing the light generated from said transmitter, by means of a lens system, onto said optical structure.

35. The method as in claim 34, wherein said light is focused by said lens system onto said optical structure as a focused dot or bar.

36. The method as in one of the claims 33-35, wherein said calculated values regarding said motion and/or position of said diaphragm or said moving-coil system comprise the speed of said motion.

37. The method as in one of the claims 33-35, wherein said calculated values regarding said motion and/or position of said diaphragm or said moving-coil system comprise the velocity of said motion.

38. The method as in one of the claims 33-35, wherein said calculated values regarding said motion and/or position of said diaphragm or said moving-coil system comprise the position of said diaphragm or said moving-coil system.

39. The method as in one of the claims 33-35, wherein said calculated values regarding said motion and/or position of said diaphragm or said moving-coil system comprise the movement vector, the velocity, and the two-dimensional position changes of said diaphragm or said moving-coil system.

40. A method to reduce acoustic distortion in a sound system of the moving-coil type, said method comprising the steps:

generating light, by means of a transmitter mounted on the non-moving part of said sound system,

reflecting and/or letting pass, by means of an optical structure constructed on the moving-coil system of said sound system, the light generated by said transmitter,

sensing the light reflected and/or let pass by said optical structure, by means of at least one photo-sensor, and generating electrical signals accordingly,

calculating, by means of a signal processing circuitry, values regarding the motion and/or position of the diaphragm or said moving-coil system of said sound system, based on said electrical signals from said at least one photo-sensor, and generating a motion correction signal accordingly,

mixing said motion correction signal, by means of a signal mixer, with the input signal to said sound system, and

feeding said mixed signal as a corrected input signal to said sound system.

41. The method as in claim 40, wherein said signal mixer is a multiplicator.

42. The method as in claim 40, wherein said signal mixer is an adder.

43. The method as in one of the claims 40-42 comprising an addition step between said light-generating step and said light-reflecting/light-passing step, for focusing the light generated from said transmitter, by means of a lens system, onto said optical structure.

44. The method as in claim 43, wherein said light is focused by said lens system onto said optical structure as a focused dot or bar.

45. The method as in one of the claims 40-44, wherein said calculated values regarding said motion and/or position of said diaphragm or said moving-coil system comprise the speed of said motion.

46. The method as in one of the claims 40-44, wherein said calculated values regarding said motion and/or position of said diaphragm or said moving-coil system comprise the velocity of said motion.

47. The method as in one of the claims 40-44, wherein said calculated values regarding said motion and/or position of said diaphragm or said moving-coil system comprise the position of said diaphragm or said moving-coil system.

48. The method as in one of the claims 40-44, wherein said calculated values regarding said motion and/or position of said diaphragm or said moving-coil system comprise the movement vector, the velocity, and the two-dimensional position changes of said diaphragm or said moving-coil system.

49. The method as in one of the claims 40-44, wherein said calculating step further comprises the steps:

receiving said electrical signals from said at least one photo-sensor,

generating a velocity signal based on said electrical signal, by means of frequency/voltage conversion and phase detection,

generating an acceleration signal, by means of taking the time derivative of said velocity signal, and

generating a difference signal, by means of comparing said acceleration signal with the original input signal to said sound system, said difference signal being said motion correction signal.

FIG 1

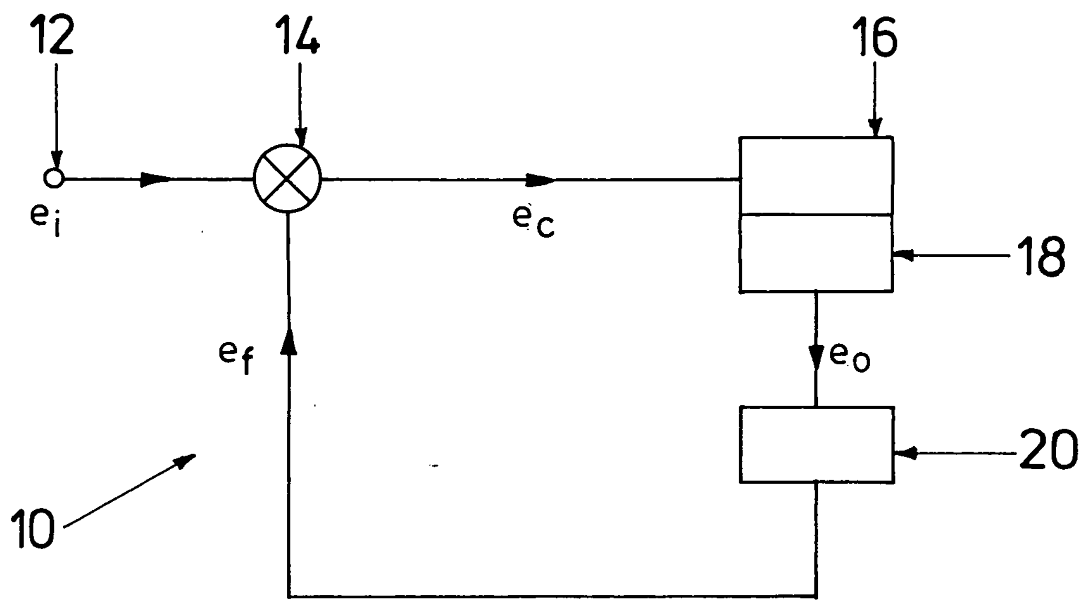


FIG 2

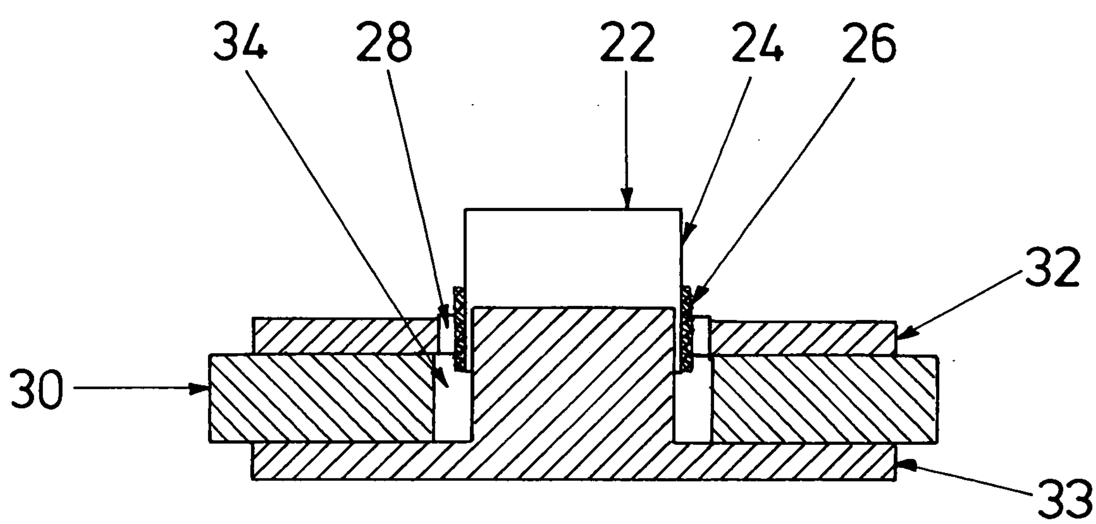


FIG 3

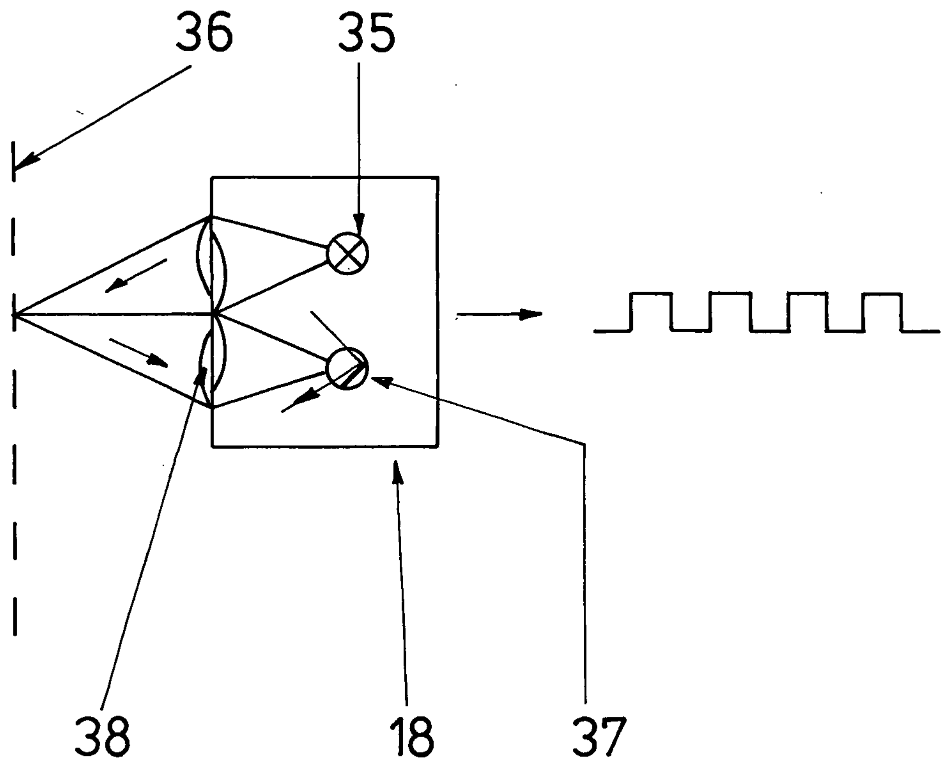


FIG 4

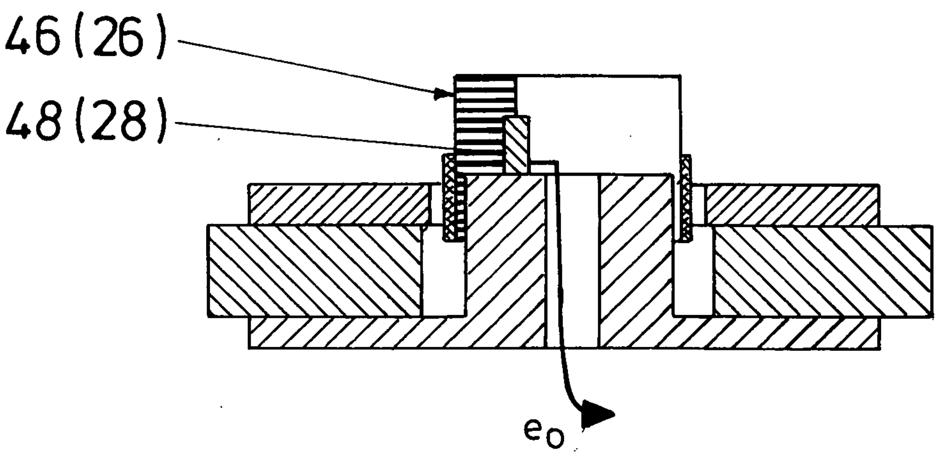


FIG 5

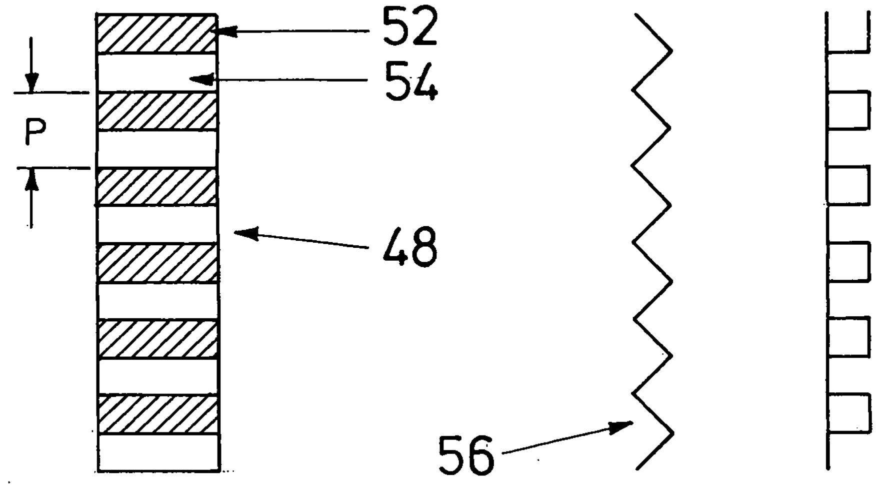


FIG 6

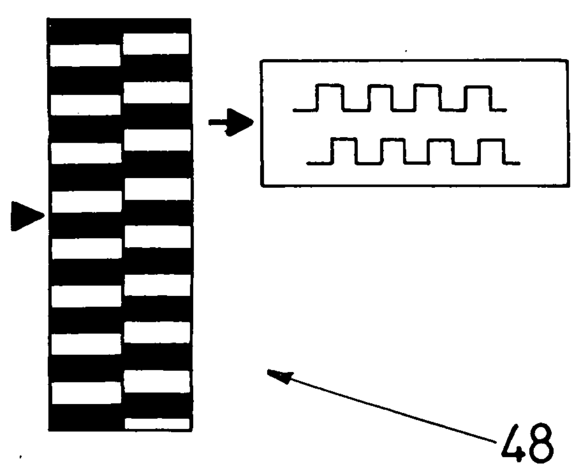


FIG 7

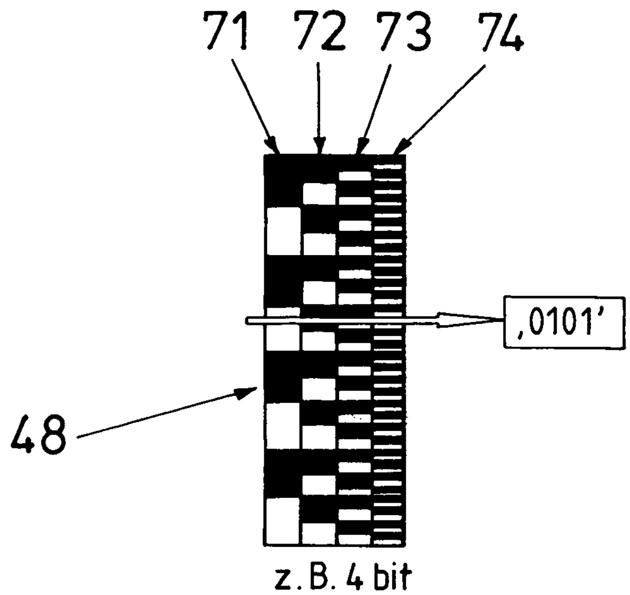


FIG 8

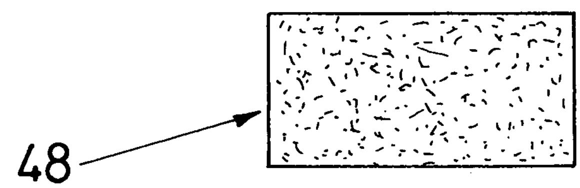


FIG 9

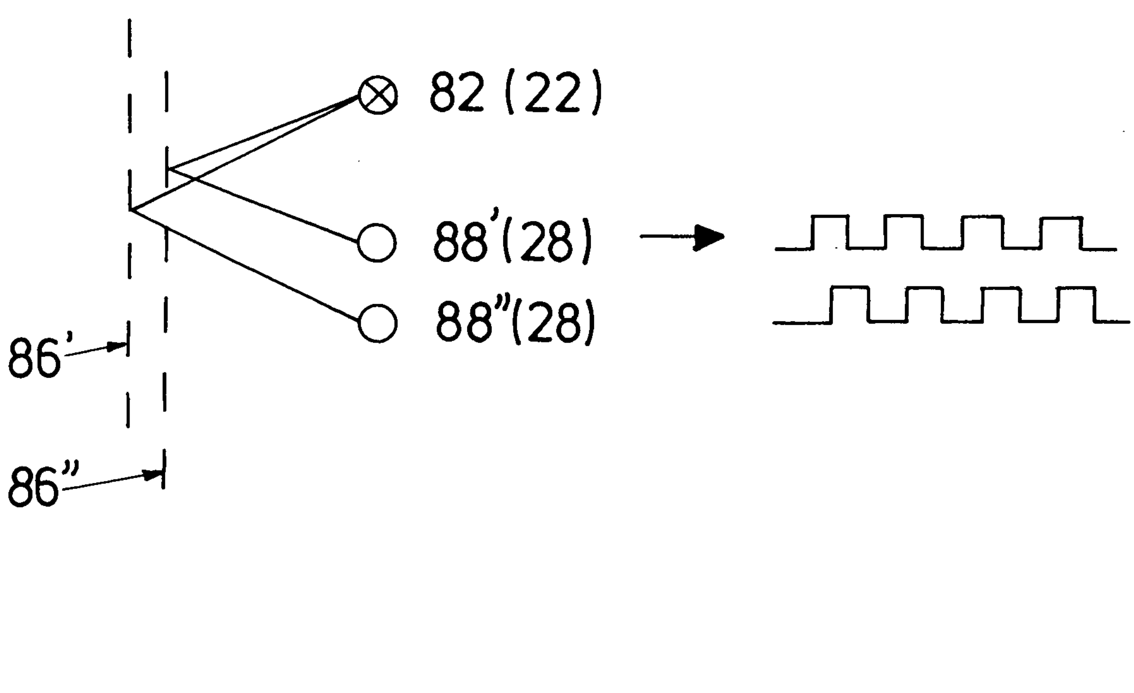
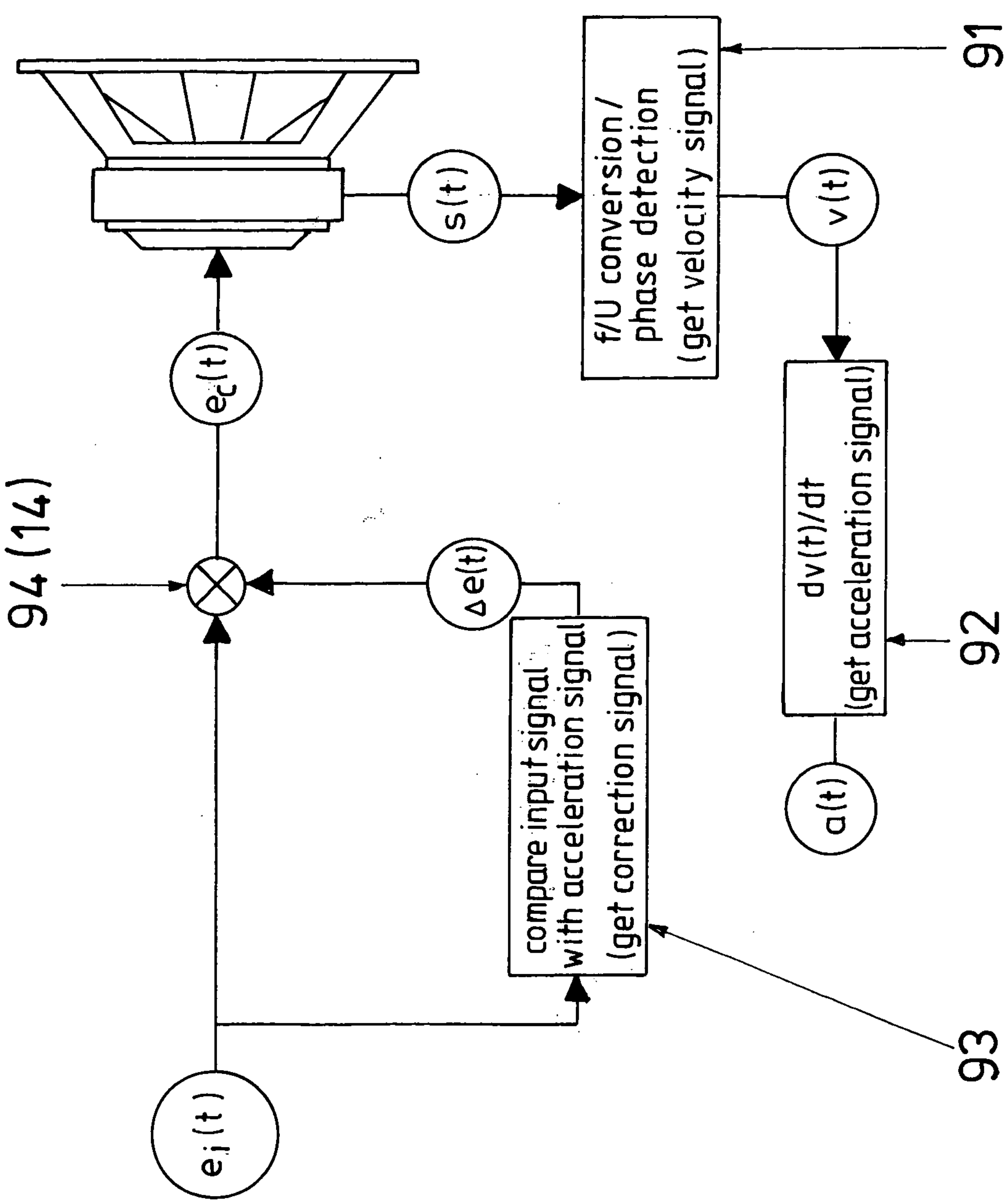


FIG 10


$e_i(t)$
compare input signal
with acceleration signal
(get correction signal)
93
$\Delta e(t)$
94 (14)
$e_c(t)$
s(t)
f/U conversion/
phase detection
(get velocity signal)
91
v(t)
dv(t)/dt
(get acceleration signal)
92
a(t)

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EUROPEAN SEARCH REPORT

Application Number
EP 04 00 4207

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	28 June 2004	Kunzelmann, C

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