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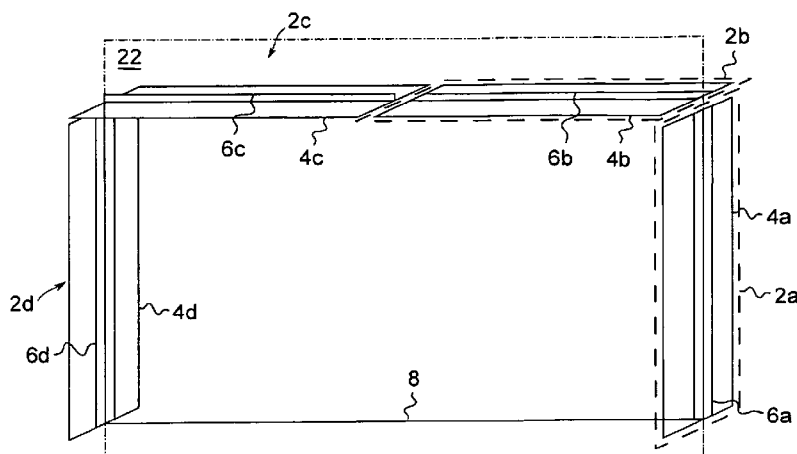


Fig. 1

(57) Abstract: An antenna system (2a-d) for determining a transit of a moving object (11) through an area of interest within a detection plane (22), the moving object (11) emitting an electromagnetic field (12), comprises at least one loop antenna (4c) for receiving the electromagnetic field (12), the at least one loop antenna (4c) comprising one or more antenna loops arranged only within an antenna plane, the antenna plane being perpendicular to the detection plane (22). The at least one loop antenna (4c) further comprises a signal terminal (60) for providing a receive signal (44a, 44b), the receive signal (44a, 44b) comprising information on a position of the moving object (11).



Antenna System and method for determining a transit of a moving object through an area of interest

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Background

Embodiments of the present invention relate to an antenna system for determining a transit of a moving object through an area of interest within a detection plane and to a method for determining said transit.

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Applications, where objects are monitored with respect to their movement are numerous, as for example in sports games. Sports games, such as for example soccer, football, handball, ice hockey, hockey or the like employ rules where one participating party scores when an object, such as a ball or the like, crosses a predetermined detection plane, as for example the open front face of a goal in soccer. The question whether the ball completely passed the plane bordering the goal is of utmost importance to conclude whether the score has been achieved or not. Traditionally, that decision has been taken by a referee from a visual observation. Especially in scenarios where the ball moves into the direction of the goal and is returned quickly by the goal keeper, it is difficult to determine, whether the ball entered completely into the goal, which is whether the ball moved completely through the detection plane.

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Apart from camera-based optical systems, some approaches propose to detect the transition of the ball through a detection plane using electromagnetic fields and/or signals derived therefrom. Some proposed systems provide magnetic fields of different direction on opposite sides of the detection plane together with sensors within the moving object or the ball under observation. That is, a sensor within the object monitors the magnetic field and determines that it passed through the detection plane when the orientation of the magnetic field has changed. In that event, the moving object or a sender contained therein transmits the information that the moving object detected transition through the detection plane to a receiver circuit such as to be able to indicate whether the ball was fully inside the volume of the goal or not.

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Other systems utilize two antenna loops on each side of the detection plane, wherein each antenna loop receives a high-frequency signal with opposite phase such as to provide magnetic fields cancelling each other out in the detection plane in the middle between the two loops. A third receive antenna loop is deployed at this position in order to receive the field disturbance of a moving object passing through the set-up such as to be able to conclude, on occurrence of a signal on the receive antenna loop, that a ball or a moving object passed the plane of the receive antenna loop.

10 In order to provide or to receive the magnetic field used for the detection, those systems utilize antenna loops fully encircling the area of interest within the detection plane, such as for example the open mouth of a soccer goal in order to provide a field of precisely predetermined geometry. By relying on the precise generation of a magnetic field of predetermined geometry, in particular with respect to the detection plane where a disappearing magnetic field is required, those systems suffer from a decreased spatial resolution, since the generation of such a precise field configuration over large areas is hardly feasible.

That is, there is a desire to provide an antenna system and a method for determining the transit of a moving object through an area of interest within a detection plane having a better characteristic.

Summary

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According to some embodiments of the present invention this is, for a moving object emitting an electromagnetic field, achieved by an antenna system, wherein the antenna system comprises at least one loop antenna for receiving the electromagnetic field, the at least one loop antenna comprising one or more antenna loops arranged only within an antenna plane which is perpendicular to the detection plane. That is, a loop antenna is utilized to detect a magnetic field component of an electromagnetic field wherein the orientation of the loop antenna, that is the area bordered by the conductors of the antenna loops is perpendicular to the detection plane. By utilizing such a loop antenna, the an-

tenna is sensitive to a field component of the magnetic field emitted by the moving object which is parallel to the detection plane. Embodiments of the present invention determine, whether a phase condition of a receive signal received at a signal terminal of the loop antenna changes according to a predetermined condition.

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According to some embodiments, this field component undergoes a change in its direction when the moving object transits through the detection plane. That is, the receive signal at the signal terminal of the loop antenna undergoes a phase change when the moving object moves through the detection plane. A phase change can be determined with utmost
10 precision, enabling the determination whether the moving object has passed through the detection plane with high precision. Moreover, the occurrence of the phase condition or the phase change is independent from the precision with which a magnetic field is provided within the detection plane. That is, the transit of a moving object through an area of interest within a detection plane may be determined with a higher precision. According to
15 some embodiments, the at least one loop antenna comprises precisely one antenna loop.

According to some embodiments, the loop antenna is furthermore operable to emit an exciting electromagnetic field, the exciting electromagnetic field exciting the moving object to the emission of the electromagnetic field. That is, when moving objects not em-
20 ploying their own energy sources are utilized, the exciting electromagnetic field may provide the energy for the moving object such as to enable the moving object to emit an electromagnetic field. According to those embodiments, the exciting electromagnetic field is provided by the same loop antenna utilized to receive the electromagnetic field emitted by the moving object. To this end, cross-talk signals may be avoided which may
25 disturb the reception of the electromagnetic field of the moving object. Cross-talk signals may otherwise occur, when the exciting electromagnetic field would be generated by an independent exciter loop. Emitting a magnetic field by means of a moving object may, therefore, be understood to be the generation of a magnetic field and/or an electric field by means of a sender energized by a separate energy source as well as by means of
30 backscattering an energizing magnetic and/or electric field. Emitting a magnetic field may, however, also be understood as any other mechanism employed by the moving object such as to generate a detectable receive signal in the loop antenna of the antenna system. Emitting a magnetic field does therefore also comprise the possibility to additionally

transfer information from the moving object to the antenna system by means of load modulation. To transfer information the quality factor of the resonant circuit in the moving object is modulated while a phase condition of the receive signal may still be utilized to detect the transit of the moving object through the detection plane.

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In order to provide for the possibility to emit the exciting electromagnetic field, some embodiments of the loop antenna comprise a first and a second terminal for providing an excitation signal to the loop antenna to generate the electromagnetic field. Once provided to the loop antenna, the excitation signal, which is, for example, an electromagnetic signal of alternating current, may be transferred from the first terminal to the second terminal via a first signal path and a different second signal path of the loop antenna. That is, the excitation signal may be split within the loop antenna to propagate along two separate signal paths from the first terminal to the second terminal, where the split signal paths may be summed up again. That is, both signal paths may participate in the generation of the exciting electromagnetic field in that the magnetic field and the electric field generated by both signal paths is pointing in the same direction such as to enable constructive interference or superposition of both parts. According to some embodiments, the first and second signal paths comprise a first and a second conductor segment, respectively. Each of the conductor segments extends in parallel to the detection plane and on opposite sides thereof with an essentially identical distance to said detection plane. That is, the resulting exciting electromagnetic field as generated by a superposition of the magnetic fields corresponding to the two signal paths transits through the detection plane in a direction perpendicular to said detection plane with a high field strength.

25 Therefore, a moving object energized by said exciting electromagnetic field, as for example an object embodying an RFID tag or the like, experiences a high field strength at the position where the transition through the detection plane occurs. To this end, problems arising from configurations where the field strength of the exciting electromagnetic field experiences a minimum at this position may be avoided. According to some embodiments, a sports equipment such as a ball or the like is utilized which embodies three loop antennas arranged in a pairwise perpendicular orientation with respect to each other. The three antennas are connected in series with a resonator, the resonator having a resonance frequency corresponding essentially to the frequency of the exciting electromag-

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netic field. Such a configuration, for example, provides for the possibility to emit an electromagnetic field from the moving object by means of so-called back-scattering. When the moving object approaches the antenna system, current is induced in the coils of the moving object and the received energy is stored in the resonant circuit containing the
5 coils and, for example, a capacitor.

The stored energy is then generating a magnetic field in the perpendicular loop antennas which superimposes such that the resultant emitted magnetic field is directed opposite to the magnetic field component of the exciting electromagnetic field and occurring with a
10 delay corresponding to a phase shift of 90° which is caused by the properties of the resonator circuit. A phase shift of a component of the resultant emitted magnetic field which is parallel to the detection plane occurs precisely when the moving object transits through the detection plane, allowing to determine the transition of the moving object with high spatial resolution and in quasi real time.

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According to some embodiments of the present invention, the first terminal for the reception by or the provision of the excitation signal to the loop antenna is situated between two coils, wherein each coil is part of one of the first signal path and the second signal path. That is, the current provided to create the exciting electromagnetic field creates a first magnetic field in the first coil and a second magnetic field in the second coil.
20 The first and second coils have windings of opposite orientation, that is, their resultant magnetic fields have opposite directions. In order to access the receive signal, the first and second coils are, in some embodiments, part of a transformer which also comprises a third coil coupled to the first and second coils such that essentially no current is induced
25 in the third coil when the current through the first and second coils is essentially equal. That is, the total flux through the third coil turns out to be zero, when the first and second signal paths experience the same current, that is, when the loop antenna is properly balanced. To this end, a first signal terminal and a second signal terminal of the loop antenna may be coupled to opposite sides of the third coil in order to only provide a receive
30 signal indicative of a position of the moving object when the antenna is balanced.

The antenna system of some embodiments further comprises a compensation signal generator coupled to the loop antenna in order to be able to balance the antenna in different

environments, that is, in order to be able to mount the antenna to various different support structures or goals. The compensation signal generator is operable to compensate different currents in the first and second signal paths such that the currents in the first and second signal paths become essentially equal. According to one embodiment, this is
5 achieved by a compensation signal path with adjustable coupling characteristics, which is coupled to one signal path of the first signal path and the second signal path. That is, the coupling characteristics of the compensation signal path may be adjusted such as to achieve a balanced antenna, which is an antenna having identical currents in the first and second signal paths.

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To this end, some embodiments employ compensation signal generators comprising a conductor wire which is essentially parallel to one of the first signal path or the second path, while the conductor wire comprises at least one of an adjustable distance to the one signal path, an adjustable inductance and an adjustable capacitance. This may provide for
15 the possibility to balance the antenna without the need to employ expensive and energy-consuming active circuitry. Embodiments of compensation signal generators may provide for the possibility to even mount the antenna system in close proximity to metallic surfaces, such as for example metallic posts or bars of soccer goals, without losing the capability to clearly identify the electromagnetic signal of the moving object. Mounting
20 the antenna system in the proximity of metallic surfaces or objects may generate eddy currents in the objects. These, in turn, may generate a disturbing magnetic field which superimposes to the field of the object and also influences a current in the antenna loop, which may reduce the accuracy of the detection of a transit through the detection plane. Using a compensation signal generator, however, may compensate the effects of the dis-
25 turbing magnetic field.

According to some embodiments, the antenna system further comprises a calibration signal generator operable to modify the characteristics of the antenna system such that a signal is generated at the signal terminal. This may, even at a totally balanced antenna,
30 provide for the possibility to generate a signal at the signal terminal. This in turn may be utilized to determine phase delays or phase relations between the excitation signal and the receive signal, which may be variable due to the used cabling and the used amplifiers or due to other influences. That is, a possibility to derive the present phase relation is

provided such as to enable a signal evaluator coupled to the signal terminal to be tuned to the receive signal, which may be identified by means of the phase relation between the exciting signal and the receive signal.

- 5 According to some embodiments, the calibration signal generator comprises an active or passive calibration circuit, that is, particular circuitry being coupleable to the first or to the second signal path such as to be able to bring the loop antenna out of balance and to thus generate a signal at the signal terminals.
- 10 According to further embodiments, the calibration signal generator is operable to switch the first and second signal terminals to different ground loop signal paths, each of the ground loop signal paths closing an electrical circuit between the first and second terminals. To this end, a ground loop signal path leading to a field configuration of the exciting electromagnetic field which is essentially parallel to the loop antenna may be
- 15 switched to a ground loop signal path causing a significant magnetic field through the loop antenna such as to create a receive signal at the signal terminal which may be utilized for calibration.

According to further embodiments of the present invention, the antenna system comprises a further loop antenna at the border of the area of interest, wherein the further loop antenna is being employed in parallel to the detection plane and perpendicular to the antenna plane. That is, the further loop antenna may be utilized to make a further decision with respect to the position of the moving object. In particular, when the antenna system is used to determine the occurrence of a goal in a handball or soccer match, the further

25 loop antenna may be utilized to decide, whether a ball, having transited through the detection plane, ended up inside the goal or outside the goal. To this end, the further loop antenna may be provided at the border of the area of interest, e.g. at the border of the goal.

- 30 According to some embodiments, a signal evaluator coupled to the signal terminal of the antenna system is, therefore, operable to determine a signal indicative of the moving object transiting through the area of interest when a phase condition of the receive signal received at the signal terminal changes according to a predetermined condition. Accord-

ing to some embodiments, the predetermined condition is a phase shift from positive to negative or vice-versa. That is, embodiments of a method for determining the transit of a moving object through an area of interest within a detection plane comprise determining a component of interest of the magnetic field, the component of interest being parallel to the detection plane. The method further comprises providing a signal indicative on the transit of the moving object through the area of interest when a phase condition of the observed component of interest changes according to a predetermined condition.

According to some embodiments, an antenna system is utilized to determine the transit of a moving object through an area surrounded by or associated to a support structure. To this end, the antenna system may further comprise a mounting structure adapted to mount the antenna system to a support structure such that the detection plane has a predetermined distance to a predetermined position at the support structure. According to some embodiments, where the antenna system is utilized to determine the occurrence of a goal in a soccer match, the predetermined distance corresponds to half a diameter of a soccer ball wherein the support structure to which the antenna system is mounted is a post or a bar of the soccer goal itself. To this end, the predetermined distance may be half a diameter of the ball, wherein the predetermined position at the support structure may be the open face of the goal facing to the soccer field.

According to some embodiments, the resonance frequency of a resonator of a movable sports equipment being observed by antenna systems according to the present invention is from the range of 10 kHz to 300 KHz in order to avoid a disturbance or interference to the system due to the presence of human beings in the proximity of the antenna system.

Brief description of the Figures

Some embodiments of apparatuses and/or methods will be described in the following by way of example only, and with reference to the accompanying figures, in which

Fig. 1 shows a schematic view of a goal of a soccer field having mounted thereto an embodiment of an antenna system;

Fig. 2 shows a sideview of a section of the antenna system as attached to the goal;

Fig. 3 shows an example of idealized signal characteristics of an excitation signal and a receive signal;

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Fig. 4 shows a perspective view of an embodiment of an antenna system as mounted to a goal;

Fig. 5 shows a schematic view of a goal equipped with an embodiment of an antenna system and an illustration of the determined receive signals;

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Fig. 6 shows a more detailed view of the signals as generated when the ball transits through the detection plane in the embodiment of Fig. 5;

15 Fig. 7 shows a circuit diagram of an embodiment of an antenna system;

Fig. 8 shows an implementation of a calibration signal generator for generating a calibration signal;

20 Fig. 9 shows a flow chart of an embodiment of a method according to the present invention; and

Fig. 10 shows an embodiment of a sports equipment operable to emit an electromagnetic field according to the present invention.

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Fig. 1 shows a schematic view of a goal, e.g. of a soccer game, having mounted thereto four antenna systems 2a-d according to an embodiment of the present invention. Although the goal is enclosed by four antenna systems in Fig. 1, further embodiments may also utilize different amounts of antenna systems. For example, in a further embodiment, only one antenna system may be used, either at one of the posts of the goal or at the top bar of the goal. In the embodiment of Fig. 1 the antenna system serves to determine the transit of a ball through an area of interest within a detection plane. In the configuration

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of Fig. 1, the detection plane is the plane perpendicular to loop antennas 4a-d of the antenna systems 2a-d and, therefore, parallel to the open front face of the goal.

As elaborated on in the following description of Figs. 2 to 6, the loop antennas 4a-d are the antennas used for the detection of the crossing or of the transit of the ball 11 through the detection plane. Therefore, the loop antennas 4a-d may also be denoted as goal line antennas. The embodiments of Fig. 1 further comprise a further loop antenna 6a-d in each of the antenna systems 2a-d, which comprises one or more antenna loops arranged only within a further antenna plane which is perpendicular to the antenna plane of the loop antennas 4a to 4d and parallel to the detection plane 22. These further loop antennas may serve to derive an information whether the ball passed through the detection plane 22 inside the goal or outside of the goal. Therefore, the further loop antennas 6a-d may also be denoted as frame antennas. In other words, the frame antennas serve to define an area of interest within the detection plane, in order to be able to conclude, whether the ball crossed the detection plane within the area of interest. Therefore, the further loop antennas 6a-d are situated at the border of the area of interest, that is, at the goal posts.

Fig. 1 further illustrates schematically a ground loop signal path 8, which serves to connect first and second terminals of the loop antennas 4a-d such as to close a conductive loop in order to generate an exciting electromagnetic field as illustrated in Fig. 2. That is, the ground loop signal path 8 closes the electrical circuit in order to enable the generation of the exciting electromagnetic field with the loop antennas 2a-d.

Although the embodiments illustrated herein utilize the loop antennas 4a-d to also generate the exciting electromagnetic field by applying an excitation signal to said loop antennas 4a-4d, further embodiments may utilize a separate excitation loop in order to provide the exciting electromagnetic field.

In the following, the operating principles of the antenna system and of the determination of the presence of a crossing or of a transit of a moving object through the area of interest within the detection plane 22 will be explained together with the discussion of Figs. 2 to 6.

With an antenna system according to the present invention, an exciting electromagnetic field which has field lines of the magnetic component that cross the detection plane 22 essentially perpendicular to the detection plane 22 may be generated. The exciting electromagnetic field 10 or, to be more precise, its magnetic component is only illustrated
5 schematically by indicating the direction of a single field line 10 in Fig. 2.

Utilizing a moving object 11 emitting a magnetic field 12 as illustrated in Fig. 2, the magnetic component 12 of the electromagnetic field is received by means of the loop antennas 4a-d. Fig. 2 assumes the moving object 11 to be a ball of sports game which
10 emits the magnetic field 12 as illustrated by the shown field lines. This may in principle be achieved by using an object 11 or a ball which is actively sending a magnetic field 12.

The embodiments described in the Figs, however, utilize a ball 11 or a moving object which is excited by the exciting electromagnetic field 10 as generated by the loop antennas 4a-d to emit the magnetic field 12. To this end, a ball or a moving object 11 as shown
15 in Fig. 10, left illustration, may be utilized, which comprises three loop antennas 14a-c being arranged in a pairwise perpendicular orientation with respect to each other. The three loop antennas 14a-c are connected in series with each other and with a resonator 16, the resonator 16 having a resonance frequency corresponding essentially to the frequency
20 of the exciting electromagnetic field 10. That is, the object has three perpendicular coils 14a-c with a resonance frequency corresponding to the frequency of the exciting electromagnetic field 10. When such a ball or object 11 approaches the goal or the antenna system 2a-d, the coils 14a-c inside the ball 11 are stimulated by the exciting electromagnetic field 10. That is, a current is induced in the loop antennas 14a-c. Due to the reso-
25 nance frequency of the resonator of the moving object 11 and the corresponding frequency of the exciting electromagnetic signal 10, the received energy is stored in the resonant circuit or in the resonator 16 of the moving object, e.g. in a capacitor used therein. The oscillation in the resonator or the stored energy is then generating a magnetic field in the coils 14a-c of the moving object 11 itself, having field lines 12 with a direction oppo-
30 site to the direction of the field lines of the exciting electromagnetic field 10.

According to further embodiments, the moving object comprises three loop antennas or coils 14a-c which are being arranged in a pairwise perpendicular orientation with respect

to each other and which are not connected in series, as indicated by the right illustration in fig. 10. Each loop antenna or coil 14a-c forms an independent resonator which further comprises an associated capacitance 16a-c being connected in series or in parallel. Each of the three so provided resonant circuits is tuned to the frequency of the exciting electromagnetic field 10 by choosing the capacitances and the inductances of the loops of each circuit appropriately.

Due to the properties of the resonator, the magnetic field 12 emitted by the moving object 11 is delayed with respect to the exciting electromagnetic 10 field by a time corresponding to a phase shift of 90° ($\pi/2$). This stimulation of the emission of a magnetic field 12 is also utilized in Radio Frequency Identification systems (RFID) in order to transmit information from objects not having embodied own energy sources. In RFID, the excited emission of a magnetic field 12 as illustrated in Fig. 2 is also known as “backscattering”. The backscattered or emitted magnetic field 12 of the moving object 11 is, amongst others, received by the loop antenna 4c which is mounted behind a goal post or a bar 18 of a goal. While the loop antennas 4a-d of the antenna systems illustrated in the Figs. do only comprise one single antenna loop formed by a conductor, further embodiments may also utilize loop antennas having more loops. Fig. 3 illustrates an idealized phase relation between an excitation signal 28 used to generate the exciting electromagnetic field 10 and a receive signal 29 as it may be received at a signal terminal of the loop antenna 4c.

Utilizing a moving object 11 as, for example the one illustrated in Fig. 10 leads to a field configuration of the magnetic field 12 emitted by the moving object 11 as illustrated in Fig. 2. This is due to the cause that the individual electromagnetic fields emitted by the three loop antennas 14a-c superimpose with each other such as to arrive at the field configuration of Fig. 2. One exemplary field strength vector 20 of the emitted magnetic field 12 is illustrated in Fig. 2, which is composed of a first component 20a in parallel to the detection plane 22 as well as of a second component 20b perpendicular to the detection plane 22. Due to its orientation, the loop antenna 4c is sensitive to the first component 20a, which is, therefore, also denoted as the goal line part, whereas the second component 20b is also denoted as the frame part of the field strength vector 20 ($H_{\text{back,ball}}$).

In other words, the backscatter signal of the moving object 11 or the ball is inducing a current into the loop antenna 4c and the further loop antenna 6c of the antenna system 2c. The further loop antenna 6c is only illustrated schematically and for the sake of completeness in Fig. 2. The backscattered or received signal can be split into a frame part 20b and a goal line part 20a. Depending on the position of the ball, the orientation of the H-field vector 20 of the backscatter signal is changing. As soon as the ball is passing the detection plane 22 at the center of the loop antenna 4c, the first component 20a of the field strength vector ($H_{\text{back,goal}}$) is crossing zero and the signal waveform is inverted. That is, a phase condition of the receive signal changes according to a predetermined condition. The predetermined condition is, according to the embodiment of Figs. 2 to 6, that the signal waveform is inverted and that the phase undergoes a change of 180° . Once a phase inversion or a phase shift of 180° occurs or is determined by evaluation of the receive signal provided by the antenna system 2c, in particular by the loop antenna 4c, a goal can be assumed, since the center of the ball or of the moving object 11 crossed the line of symmetry of the two signal paths of the loop antenna 4c, that is the detection plane 22. However, at the time of the crossing, the overall field strength of the exciting electromagnetic field 12 is at maximum and, therefore, the emission of the magnetic field 12 of the moving object is maintained, increasing the achievable precision in the determination of the transit of the object 11 as compared to alternative approaches, where the exciting electromagnetic field within the detection plane 10 is tuned or adjusted to be zero.

Utilizing an antenna system according to an embodiment of the present invention, therefore, allows to determine the occurrence of a goal, that is, the fact that the complete ball 11 was, at any time instance, completely behind the goal line, with highest precision.

For the detection of a goal in a soccer game, the antenna system 4c may comprise a mounting structure operable to mount the antenna system to a support structure or to the goal such that the detection plane 22 has a distance equaling half a diameter of a soccer ball to the front face of the goal. In order to provide a more flexible solution, the mounting structure may be adjustable to fit different designs of goals, such as to be able to adjust the predetermined distance to the requirements. Fig. 4 shows a perspective view of the configuration illustrated in Fig. 2, wherein an embodiment of a mounting structure 24

adapted to mount the antenna system comprising the loop antenna 4c and the further loop antenna 6c to the aluminum bar 18 of a goal is illustrated schematically.

As further illustrated in Fig. 4, the loop antenna 4C comprises a first terminal 26a and a
5 second terminal 26b in order to receive the excitation signal 28 for the loop antenna 4c, which allows providing said excitation signal 28 to the loop antenna. As illustrated in more detail in Fig. 4, the excitation signal 28 of alternating current is split and transferred (propagates) from the first terminal 26a to the second terminal 26b via a first signal path 30a as well as via a second signal path 30b. That is, both conductors of the loop antenna
10 4c which extend in parallel to the detection plane 22 participate in the generation of the exciting electromagnetic field 10. According to the embodiment of Fig. 4, the further loop antenna 6c, that is, the frame antenna, does not participate in the generation of the electromagnetic field 10. However, further embodiments may also utilize the further loop antenna 6c for the generation of the exciting electromagnetic field 10.

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Fig. 4 further illustrates a compensation signal path 32, which is coupled to the second signal path 30b and which serves to balance the loop antenna 4c. In alternative embodiments, the compensation signal path 32 may, of course, also be coupled to the first signal path 30a. The compensation signal path 32 has adjustable coupling characteristics with
20 respect to the second signal path 30b. This may be utilized to compensate for field components generated by eddy currents in metallic posts such as for example in the aluminum post 18 illustrated in Fig. 4. The eddy currents may, for example, be generated by the current in the first signal path 30a and, hence, induce a current into the loop antenna 4c which is not caused by the moving object and, therefore, undesirable. By means of the
25 compensation signal path 32, or, more generally, by using a compensation signal generator within the antenna system 2c, such signal components may be compensated so that the antenna is balanced, that is, one of the signal paths 30a or 30b carries half of the current of the excitation signal 28, while the other signal path, possibly together with the compensation signal path 32 or with the compensation signal generator carries the other
30 half of the current, such that no signal is induced in the loop antenna 4c without the presence of the moving object 11 in the proximity of the loop antenna 4c. To this end, the loop antenna is tuned such that the both signals carrying half of the current each, are in phase.

Fig. 4 shows one particular possibility to implement a compensation signal generator by using a compensation wire having an adjustable distance to the wire of the second signal path 30b and/or an adjustable inductance so that the antenna can be balanced by adjusting the distance and/or the inductance once the antenna is mounted to the support structure or to the goal. A further possibility to implement a compensation signal generator would, for example, be to add a symmetric metal or aluminum part on the other side of the antenna system 2c such as to provide a symmetric configuration in which the eddy currents of the different metal bars compensate each other. A further possibility to implement a compensation signal generator would, for example, be to induce a current into the loop antenna 4c or into one signal path of the loop antenna 4c with an appropriately adjusted amplitude and phase generated such that the influence of the eddy current is compensated for. The induction of this additional compensation signal could, for example, be performed by means of a further transformer or the like. However, when using a compensation signal path 32 or a compensation wire as illustrated in Fig. 4, and, in more detail in Fig. 7, no further active signal path is necessary and, hence, the antenna system remains simple and reliable.

Apart from the use of the compensation signal generator or the compensation signal path 32, the antenna system design is also highly efficient in avoiding cross-talk or undesired signal components as compared to other solutions employing an additional independent loop for the generation of the exciting electromagnetic field 10. Using an additional loop may generate cross-talk signals in the loop antenna 4c of the antenna system 2c which might cover the magnetic field 12 of the backscatter signal of the moving object 11. This would decrease the accuracy of the detection of the occurrence of a goal significantly. However, utilizing the loop antenna to create the exciting electromagnetic field as in the embodiments described in the Figs. avoids the occurrence of cross-talk signals due to the particular generation of the exciting electromagnetic field 10.

Fig. 5 shows, by way of example, two receive signals 42a and 42b as they may be received by the loop antenna of Fig. 4c when a ball passes a detection plane of a goal such that a score is achieved in a soccer or handball game or the like. Fig. 5 schematically shows a goal and the receive signals 42a and 42b resulting from two different positions

where a ball passes the detection plane. The first position 40a is essentially in the center of the goal while the second position 40b is close to a post of the goal. The coordinate system is chosen to be such that the X direction is the direction from the bottom to the top bar of the goal, while the Y direction extends from the left to the right and the Z direction is perpendicular to the paper plane, that is, perpendicular to the detection plane, which is parallel to the plane of the open face of the goal.

The two signal characteristics of receive signals 42a and 42b as determined by an embodiment of the antenna system are shown on top of the goal 18. The geometry is chosen such that the plane having a Z-coordinate of zero corresponds to the detection plane. As already explained in the preceding paragraphs, a receive signal 42a and 42b as determined by some antenna systems according to the present invention undergoes a phase change, that is, crosses zero when the ball crosses or passes through the detection plane. Although the amplitudes of the receive signals 42a and 42b and the distance to the detection plane that corresponds to the occurrence of a detectable receive signal (in terms of a significant amplitude produced by the moving object) may differ significantly, it becomes apparent, that irrespective of the position where the ball passes through the detection plane, the phase change precisely occurs at the position of the detection plane. This is particularly due to the geometry of the loop antennas 4a-d of the antenna system, in particular due to their orientation with respect to the detection plane and due to the generation of the exciting electromagnetic field by the loop antennas. Therefore, the reliable detection of a goal can be achieved over the complete area of interest, in particular, since a phase change, that is, the change of a phase condition of 180° (a change in sign of a particular quantity) can be sensed with high precision.

25

Fig. 6 illustrates a particular implementation as to how the detection of the phase change may be performed, which additionally allows to cancel long-term effects such as temperature-induced drifts of the system or the like. In principle, the receive signals as received at signal terminals of the loop antenna may be provided to or fed to a receiver circuit, where the backscatter signal, that is, the received signal as caused by the magnetic field 12 of the moving object 10, is down-converted coherently to a complex baseband signal. The down conversion results in a complex valued vector for the receive signal. The vector of the receive signal may be compared to the signal vector of the excitation signal

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- used to generate the exciting electromagnetic field. As illustrated in Fig. 3 for an ideal configuration, the phase shift $\Delta\varphi$ between the two vectors is 90° . However, due to differing cable length, variations and run times in the receiver circuits or similar influences, the phase shift will in general be different from 90° . The amplitude of the complex vector
- 5 representing the received signal is dependent on the position of the ball, in particular, on the distance of the ball with respect to the detection plane. As indicated already in Fig. 5, however, a phase inversion occurs when the ball passes the detection plane or the goal line.
- 10 In the goal detection algorithms, the imaginary and real parts of the complex valued baseband signal may be processed separately. That is, an algorithm used to detect the transit of a moving object 11 through the detection plane 22 may search for a zero crossing point, that is, for a configuration where the complex valued vector crosses zero due to the change of the phase condition. In order to suppress noise effects, it may additionally
- 15 be verified, whether an amplitude peak above a certain minimum threshold occurred right before the phase change or the zero crossing point. Also in order to avoid wrong detections caused by long-term drifts of the whole system, further embodiments of the present invention may utilize two different frequencies. One frequency of an excitation signal used for the generation of the exciting electromagnetic field 10 corresponds to the resonance frequency of the resonator 16 of the moving object 11 while a further frequency is
- 20 slightly below or above the resonance frequency. Therefore, the moving object or the ball is less sensitive to the second frequency which results in an emitted magnetic field inducing a receive signal of a lower amplitude as compared to the receive signal caused by the excitation signal at the resonance frequency. Drift effects, however, influence both re-
- 25 ceive signals identically and a difference between the two signal amplitudes remains the same, when changes are induced by drift effects. Hence, those changes may be identified and compensated for. If, however, a ball is approaching the goal or the detection plane 22, the difference between both signals decreases and drops to zero when the ball crosses the detection plane 22 which allows for a discrimination against drift effects.
- 30 Further embodiments avoid wrong determinations of goals by summing up the signal of the loop antenna 4c and of the further loop antenna 6c, that is, of the goal line antenna and the frame antenna to derive a complex vector indicating an orientation of the field

generated or emitted by the ball 11 and hence an indication of the position of the ball with respect to the antenna system. In particular, using estimations of field vectors as determined by multiple antenna systems may provide for the possibility to estimate the position of the ball. This information may be furthermore used as a consistency check in
5 order to avoid wrong detections of goals caused by noise or long-term drift effects.

Fig. 6 shows, for the two receive signals 42a and 42b illustrated in Fig. 5, the effect of using excitation signals of slightly differing frequency in order to generate the exciting electromagnetic field 10. The response, that is, the receive signal caused by the electro-
10 magnetic field, excited with the resonance frequency is shown in a first graph 44a, while the receive signal caused by an excitation signal with slightly different frequency is illustrated by a second graph 44b. As illustrated in Fig. 6, the two signals show the signal characteristics elaborated on above and hence allow to avoid wrong detections of goals.

15 Fig. 7 shows a circuit diagram of an embodiment of the present invention, showing the individual components of an antenna system 2c according to an embodiment of the present invention and the coupling to its environment.

For the simplicity of the illustration, only the loop antenna 4c is illustrated in Fig. 7,
20 while the further loop antenna 6c, that is the frame antenna, is not shown, since this antenna need not be balanced or compensated with the same precision as the goal line antenna 4c. The loop antenna comprises the first signal path 30a and the second signal path 30b. The transmission properties of the first and second signal paths 30a and 30b are illustrated by corresponding first and second inductances 46a and 46b as well as by cor-
25 responding first and second resistances 48a and 48b. As already mentioned before, the excitation signal 28 is split at the first terminal 26a such as to utilize both signal paths 30a and 30b for the generation of the exciting electromagnetic field 10. The signal of both signal paths 30a and 30b is summed up at the second terminal 26b where the current source providing the excitation signal 28 connects. The influence of metallic post of a
30 goal or the like is modelled by the inductive coupling between an inductance 50 of the aluminum post which is connected in series to an associated resistance 52. In order to compensate for the influence of the post the antenna system illustrated in Fig. 7 incorporates a compensation signal path 32, connected in parallel to the second signal path 30b.

The compensation signal path 32 has associated thereto an inherent resistance 54 and an inherent inductance 56. A distance between the compensation signal path 32 and the second signal path 30b may, according to some embodiments, be adjustable in order to compensate for the influence of the eddy currents in the aluminum post. According to

5 further embodiments, the compensation signal path 32 may furthermore comprise a variable inductance 58, such as to be able to compensate the influence of the aluminum post or of other influences more precisely. In other words, an additional wire may be used, which is running or extending in parallel to the second signal path 30b of the antenna loop 4c and which builds a coupling circuit ($L_{\text{goal}2}$, L_{comp} , $M_{\text{com,var}}$). By changing the distance

10 between the compensation wire and the antenna loop 4c, the coupling factor $M_{\text{comp,var}}$ can be adjusted. In addition or alternatively, a variable inductor 58 or a variable capacitance may be implemented into the compensation path 32. The two variable elements $L_{\text{comp,var}}$ and $M_{\text{comp,var}}$ may be tuned in a way that both sides of the loop, that is, the first signal path 30a at the first side of the detection plane 22 and the second signal path

15 30b in combination with the compensation signal path 32 at the opposite side of the detection plane 22 are balanced. That is, in the balanced situation, $I_{\text{TX1}} = I_{\text{TX2}} = 1/2 \cdot I_{\text{exc}}$, with the current signals being in phase.

The loop antenna 4c furthermore comprises a signal terminal 60 comprising a first signal

20 terminal 60a and a second signal terminal 60b in order to provide the receive signal of the loop antenna 4c. The receive signal is coupled out of the loop antenna 4c by means of a transformer 62. The transformer 62 is formed by a first coil 64a and a second coil 64b as well as by a third coil 66. The first coil 64a is part of the first signal path 30a and the second coil 64b is part of the second signal path 30b, wherein the first terminal 28 is situated

25 between the first and second coils 64a and 64b. The first and second coils 64a and 64b are, however, wound with different orientations, that is, the third coil 66 is coupled to the first and second coils 64a and 64b such that essentially no current is induced in the third coil 66 when the current through the first and second coils 64a and 64b is essentially equal, that is, when the antenna is balanced. Therefore, in the situation of a balanced

30 antenna, no current is induced in the third coil 66 and hence no significant receive signal is provided at the first and second signal terminals 60a and 60b when the moving object is not present or close.

In order to be able to perform the above discrimination of the receive signal 29 and hence the determination of a transit of the ball 11 through the detection plane 22, however, knowledge on a phase relation between the excitation signal 28 and a receive signal 29 as provided at the signal terminals 60a and 60b may be desirable. Arbitrary amplitude and phase distortion may be employed due to a delay in the antenna cables or in the receiving path of a receiver coupled to the signal terminal 60. These may need to be compensated. In the desirable configuration of a fully-balanced antenna system, however, no signal is present at the signal terminals 60a and 60b which may be utilized for the determination of the phase relation.

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In order to provide for the possibility of such a calibration, further embodiments of the present invention optionally comprise a calibration signal generator 69 which is operable to modify the characteristics of the antenna system such that a signal is generated at the signal terminals 60a and 60b.

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According to some embodiments, this may be achieved by switchable tuning elements in one of the first or the second signal paths 30a or 30b to intentionally bring the antenna out of balance. Examples of those tuning elements may be additional inductors or coupling elements which can be switched on and off by means of relays or transistor circuits.

That is, according to some embodiments, the calibration signal generator 69 may comprise a calibration circuit being coupleable to the first or the second signal path 30a or 30b on demand.

According to another embodiment of the present invention, however, the calibration signal generator 69 allows to change the configuration of the circuitry used to generate the exciting electromagnetic field 10 such that the changed exciting electromagnetic field 10 induces a minor amount of current into the loop antenna 4c and, optionally, also in the further loop antenna 6c (the frame antenna). Different exciter loop configurations may be changed by means of a relay or transistor circuitry, which is capable of switching between at least two different configurations. According to the embodiment of Fig. 8, the calibration signal generator 69 is operable to select one of two different ground loop signal paths 70a and 70b. In the configuration of the first ground loop signal path 70a, the field vector 72 of the magnetic component of the exciting electromagnetic field 10 as

created by the loop antenna 4c is, at the detection plane 22, perpendicular to said detection plane 22 and, therefore, no signal is induced into a balanced loop antenna 4c. In the second configuration, as illustrated in the lower illustration of Fig. 8, however, a second ground loop signal path 70b is chosen such that the field vector 72 is slightly inclined and, hence, a signal is induced in the loop antenna 4c. The so induced signal may be utilized to determine the phase relation between the exciting signal 28 and the receive signal 29.

The antenna system of Fig 7 further comprises a signal evaluator 68 coupled to signal terminal 60 of the antenna system to evaluate the receive signal and to determine a signal indicative of the position and/ or transit of the moving object through the detection plane 22.

Fig. 9 illustrates schematically a flow diagram for a method for determining a transit of a moving object through an area of interest within a detection plane according to an embodiment of the present invention. The moving object emits a magnetic field, for example by backscattering using a configuration shown in Fig. 10. In a determination step 74, a component of interest of the magnetic field is determined, wherein the component of interest is parallel to the detection plane 22.

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In a providing step 76, a signal on the transit of the moving object through the area of interest is provided, when a phase condition of the observed component of interest changes according to a predetermined condition.

Fig. 10 shows an embodiment of sports equipment or a sensor configuration to be used with an antenna system according to any of the embodiments of the present invention which emits a magnetic field 12 used to determine the transit of the sports equipment or the moving object through the detection plane 22. The moving object or sports equipment of Fig. 10 comprises three pairwise perpendicular antenna loops 14a to 14c which are connected in series with a resonator 16 having a resonance frequency corresponding essentially to the frequency of an exciting electromagnetic field 10. According to some embodiments, the resonance frequency is within the range of 10 kHz to 300 kHz or, preferably, in the range of 30 kHz to 200 kHz, such as to use electromagnetic fields not being

disturbed by the presence of human beings, animals or other living creatures so that a reliable detection of a goal may be performed, even when the area of the goal is crowded with soccer players or other people.

5 Although primarily illustrated and explained with respect to the detection of goals in a soccer match, further embodiments of the present invention may be utilized in any other scenario where it is desirable to detect the transit of a movable object or of any kind of object through a particular detection plane. This may, for example, be any other kind of sports game, such as for example, handball, American football, polo, cricket, hockey, ice
10 hockey or the like. Furthermore, embodiments may be utilized to track the transportation of movable goods within a warehouse or the like. In another implementation, embodiments of antenna systems may be utilized to detect the crossing of joggers or cyclists or other competitors at the start line of a mass sports event or the like.

15 The description and drawings merely illustrate the principles of the invention. It will thus be appreciated that those skilled in the art will be able to devise various arrangements that, although not explicitly described or shown herein, embody the principles of the invention and are included within its spirit and scope. Furthermore, all examples recited herein are principally intended expressly to be only for pedagogical purposes to aid the
20 reader in understanding the principles of the invention and the concepts contributed by the inventor(s) to furthering the art, and are to be construed as being without limitation to such specifically recited examples and conditions. Moreover, all statements herein reciting principles, aspects, and embodiments of the invention, as well as specific examples thereof, are intended to encompass equivalents thereof.

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Functional blocks denoted as “means for ...” (performing a certain function) shall be understood as functional blocks comprising circuitry that is adapted for performing a certain function, respectively. Hence, a “means for s.th.” may as well be understood as a “means being adapted or operable for s.th.”. A means being adapted for performing a
30 certain function does, hence, not imply that such means necessarily is performing said function (at a given time instant).

Functions of various elements shown in the figures, including any functional blocks may be provided through the use of dedicated hardware, as e.g. a processor, as well as hardware capable of executing software in association with appropriate software. When provided by a processor, the functions may be provided by a single dedicated processor, by a
5 single shared processor, or by a plurality of individual processors, some of which may be shared. Moreover, explicit use of the term “processor” or “controller” should not be construed to refer exclusively to hardware capable of executing software, and may implicitly include, without limitation, digital signal processor (DSP) hardware, network processor, application specific integrated circuit (ASIC), field programmable gate array (FPGA),
10 read only memory (ROM) for storing software, random access memory (RAM), and non-volatile storage. Other hardware, conventional and/or custom, may also be included.

It should be appreciated by those skilled in the art that any block diagrams herein represent conceptual views of illustrative circuitry embodying the principles of the invention.
15 Similarly, it will be appreciated that any flow charts, flow diagrams, state transition diagrams, pseudo code, and the like represent various processes which may be substantially represented in computer readable medium and so executed by a computer or processor, whether or not such computer or processor is explicitly shown.

20 Furthermore, the following claims are hereby incorporated into the Detailed Description, where each claim may stand on its own as a separate embodiment. While each claim may stand on its own as a separate embodiment, it is to be noted that - although a dependent claim may refer in the claims to a specific combination with one or more other claims - other embodiments may also include a combination of the dependent claim with the sub-
25 ject matter of each other dependent claim. Such combinations are proposed herein unless it is stated that a specific combination is not intended. Furthermore, it is intended to include also features of a claim to any other independent claim even if this claim is not directly made dependent to the independent claim. Particularly, when a dependent claim is referring to an encoder or a sender, the corresponding feature of the related decoder or
30 receiver shall herewith also be included and part of the disclosure of the description.

It is further to be noted that methods disclosed in the specification or in the claims may be implemented by a device having means for performing each of the respective steps of these methods.

- 5 Further, it is to be understood that the disclosure of multiple steps or functions disclosed in the specification or claims may not be construed as to be within the specific order. Therefore, the disclosure of multiple steps or functions will not limit these to a particular order unless such steps or functions are not interchangeable for technical reasons.
- 10 Furthermore, in some embodiments a single step may include or may be broken into multiple sub-steps. Such substeps may be included and part of the disclosure of this single step unless explicitly excluded.

Claims

1. An antenna system (2a-d) for determining the transit of a moving object (11) through an area of interest within a detection plane (22), the moving object (11) emitting
5 a magnetic field (12), the antenna system (2a-d) comprising:

at least one loop antenna (4c) for receiving the electromagnetic field (12), the at least one loop antenna (4c) comprising one or more antenna loops arranged only within an antenna plane, the antenna plane being perpendicular to the detection plane (22); the at least one
10 loop antenna (4c) further comprising a signal terminal (60) for providing a receive signal (44a, 44b), the receive signal (44a, 44b) comprising information on a position of the moving object (11).

2. The antenna system (2a-d) of claim 1, wherein the at least one loop antenna (4c)
15 is furthermore operable to emit an exciting electromagnetic field (10), the exciting electromagnetic field (10) exciting the moving object (11) to the emission of the magnetic field (12).

3. The antenna system (2a-d) of claim 2, wherein the at least one loop antenna (4c)
20 comprises a first terminal (26a) and a second terminal (26b) for receiving an excitation signal (28) to generate the exciting electromagnetic field (10), wherein the excitation signal (28) is transferred from the first terminal (26a) to the second terminal (26b) via a first signal path (30a) and via a different second signal path (30b) of the at least one loop antenna (4c).

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4. The antenna system (2a-d) of claim 3, wherein the first signal path (30a) comprises a first conductor segment extending in parallel to the detection plane (22) and wherein the second signal path (30b) comprises a second conductor segment extending in parallel to the detection plane (22).

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5. The antenna system (2a-d) of claim 4, wherein the first signal path (30a) and the second signal path (30b) are arranged on different sides of the detection plane (22) and with essentially identical distance to said detection plane (22).
- 5 6. The antenna system (2a-d) of any of claims 3 to 5, wherein the first signal path (30a) and the second signal path (30b) are configured such that the excitation signal (28) propagates from the first terminal (26a) to the second terminal (26b) via the first signal path (30a) and the second signal path (30b) simultaneously and in phase.
- 10 7. The antenna system (2a-d) of any of claims 3 to 6, wherein the first terminal (26a) is situated between a first coil (64a) being part of the first signal path (30a) and a second coil (64b) being part of the second signal path (30b), the first coil (64a) and the second coil (64b) having windings of opposite orientation.
- 15 8. The antenna system (2a-d) of claim 7, wherein the first coil (64a) and the second coil (64b) are part of a transformer (62), the transformer (62) further comprising a third coil (66) coupled to the first coil (64a) and the second coil (64b) such that essentially no current is induced in the third coil (66) when the current through the first coil (64a) and the second coil (64b) is essentially equal.
- 20 9. The antenna system (2a-d) of claim 8, wherein the signal terminal (60) comprises a first signal terminal (60a) coupled to a first side of the third coil (66) and a second signal terminal (60b) coupled a different second side of the third coil (66) in order to provide the receive signal at the first signal terminal (60a) and the second signal terminal (60b).
- 25 10. The antenna system (2a-d) of any of the preceding claims, further comprising a compensation signal generator coupled to the loop antenna (4c), wherein the compensation signal generator is operable to compensate differing currents in the first signal path (30a) and in the second signal path (30b) such that the currents in the first signal path (30a) and in the second signal path (30b) become essentially equal.
- 30

11. The antenna system (2a-d) of claim 10, wherein the compensation signal generator comprises a compensation signal path (32) with adjustable coupling characteristics, the compensation signal path coupled (32) to one signal path of the first signal path (30a) and the second signal path (30b).

5

12. The antenna system (2a-d) of claim 11, wherein the compensation signal path (32) comprises a conductor wire being essentially parallel to one signal path of the first signal path (30a) and the second signal path (30b), the conductor wire comprising at least one of an adjustable distance to the one signal path and an adjustable inductance (58) and

10

13. The antenna system (2a-d) of any of the preceding claims, further comprising a calibration signal generator (69) operable to modify the characteristics of the antenna system (2a-d) such that a signal is generated at the signal terminal (60).

15

14. The antenna system (2a-d) of claim 13, wherein the calibration signal generator (69) comprises a calibration circuit, the calibration circuit being coupleable to the first signal path (30a) or the second signal path (30b) such that a characteristic of the respective signal path is altered.

20

15. The antenna system (2a-d) of claim 13, wherein the calibration signal generator (69) is operable to select one of a first ground loop signal path (70a) and a second ground loop signal path (70b), each ground loop signal path, when selected, closing an electrical circuit between the first terminal (26a) and the second terminal (26b) of the antenna system (2a-d).

25

16. The antenna system (2a-d) of any of the preceding claims, further comprising, at a border of the area of interest, at least one further loop antenna (6c) for receiving the electromagnetic field, the further loop antenna (6c) comprising one or more antenna loops arranged only within a further antenna plane, the further antenna plane being perpendicular to the antenna plane and parallel to the detection plane (22).

30

17. The antenna system (2a-d) of any of the preceding claims, further comprising a signal evaluator (68) coupled to signal terminal (60) of the antenna system (2a-d), the signal evaluator (68) being operable to determine a signal indicative of the moving object (11) passing through the area of interest when a phase condition of the receive signal (44a, 44b) received at the signal terminal (60) changes according to a predetermined condition.

18. The antenna system (2a-d) of claim 17, wherein the predetermined condition is a phase change of the receive signal (44a, 44b) from positive phase terms to negative phase terms or vice versa.

19. The antenna system (2a-d) of any of the preceding claims, further comprising a mounting structure (24) adapted to mount the antenna system (2a-d) to a support structure (18) such, that the detection plane (22) has a predetermined distance to a predetermined position at the support structure (18).

20. The antenna system (2a-d) of claim 18, wherein the support structure is a post or a bar (18) of a soccer goal, wherein the moving object is a soccer ball (11) and wherein the predetermined distance corresponds to half a diameter of a soccer ball.

21. Soccer goal having coupled thereto at least one of the antenna systems of any of the preceding claims at a predetermined distance to a goal line.

22. Method for determining a transit of a moving object (11) through an area of interest within a detection plane (22), the moving object (11) emitting a magnetic field (12), the method comprising:

determining a component of interest (20a) of the magnetic field (12), the component of interest being parallel to the detection plane (22); and

providing a signal indicative on the transit of the moving object (11) through the area of interest (22) when a phase condition of the observed component of interest (20a) changes according to a predetermined condition.

23. Method of claim 22, wherein determining the component of interest comprises receiving the component of interest (20a) with at least one loop antenna, the at least one loop antenna having one or more antenna loops arranged only within an antenna plane, the antenna plane being perpendicular to the detection plane (22).

24. Sports equipment operable to emit a magnetic field (12) in response to an exciting electromagnetic field (10), the sports equipment comprising:

10 three loop antennas (14a-c) being arranged in pairwise perpendicular orientation with respect to each other, the three loop antennas (14a-c) being coupled to a resonator (16), the resonator (16) having a resonance frequency corresponding essentially to the frequency of the exciting electromagnetic field (10).

15 25. Sports equipment of claim 24, wherein each loop antenna (14a-c) is connected in series or in parallel to an associated capacitance (16a-c) such as to form three independent resonators, each having a resonance frequency corresponding essentially to the frequency of the exciting electromagnetic field (10).

20 26. Sports equipment of claim 24 or 25, wherein the resonance frequency is from the range of 10kHz to 300kHz or from the range of 30kHz to 200kHz.

27. A computer program for, when running on a computer, performing a method according to any of claims 22 and 23.

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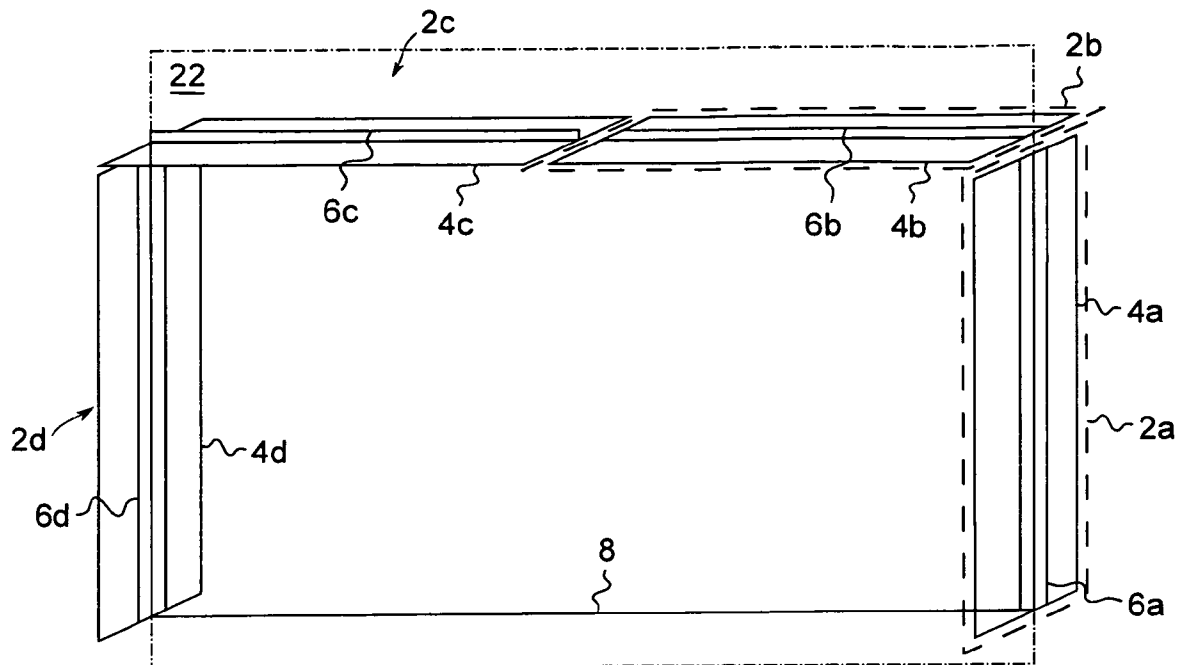


Fig. 1

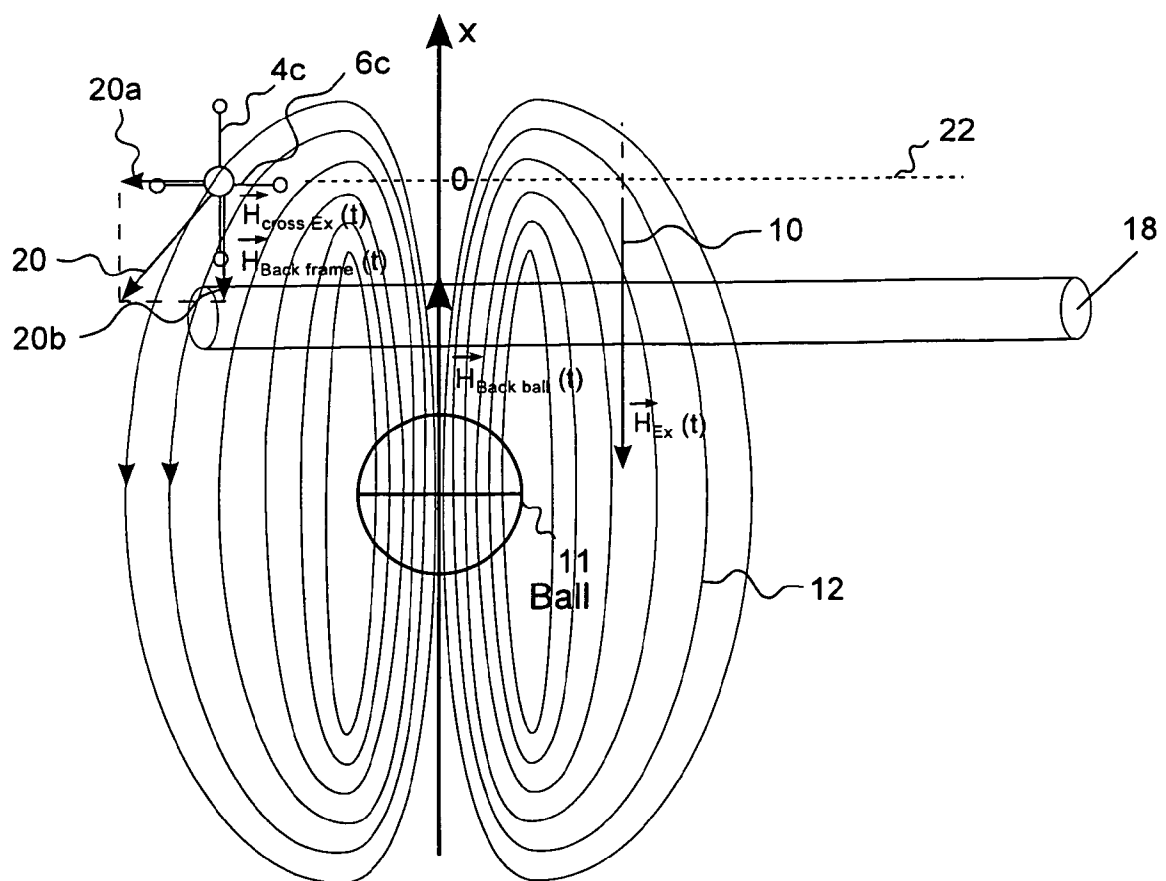


Fig. 2

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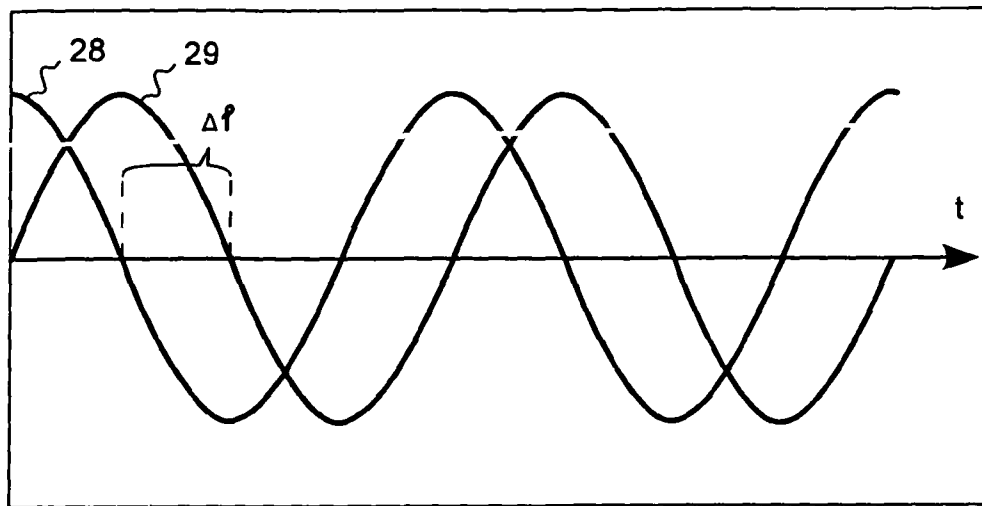


Fig. 3

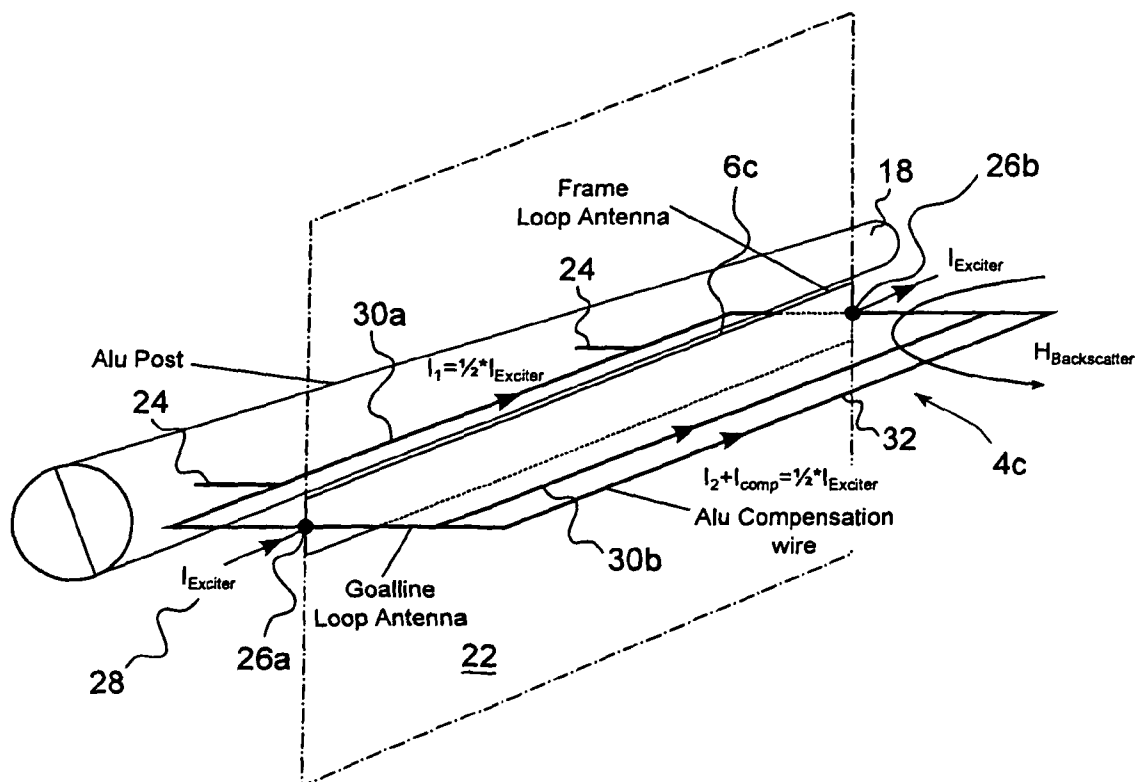


Fig. 4

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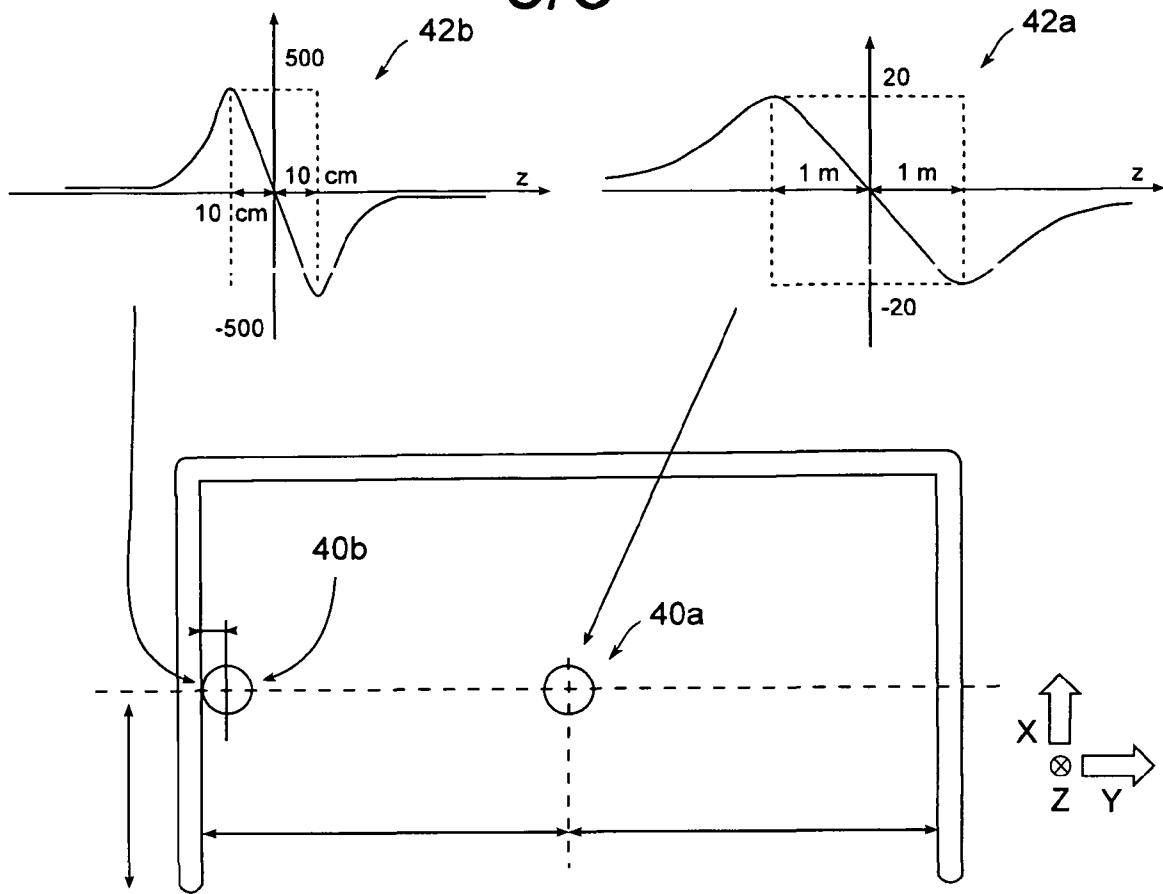


Fig. 5

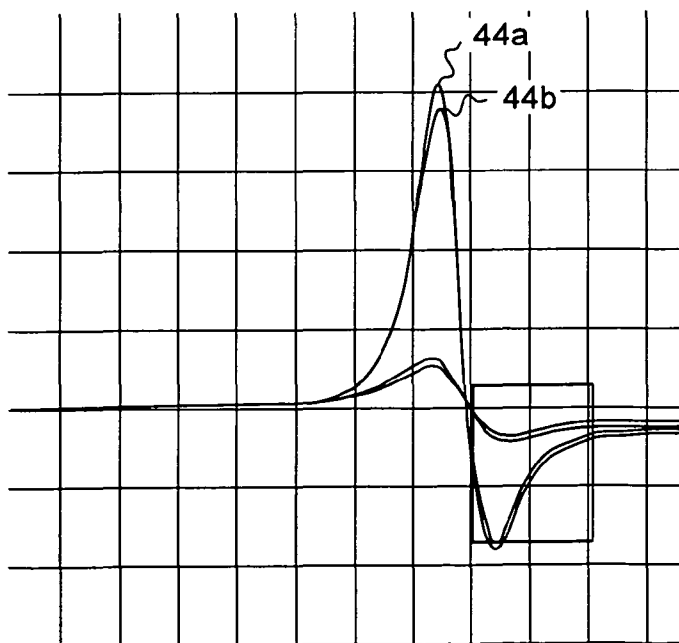


Fig. 6

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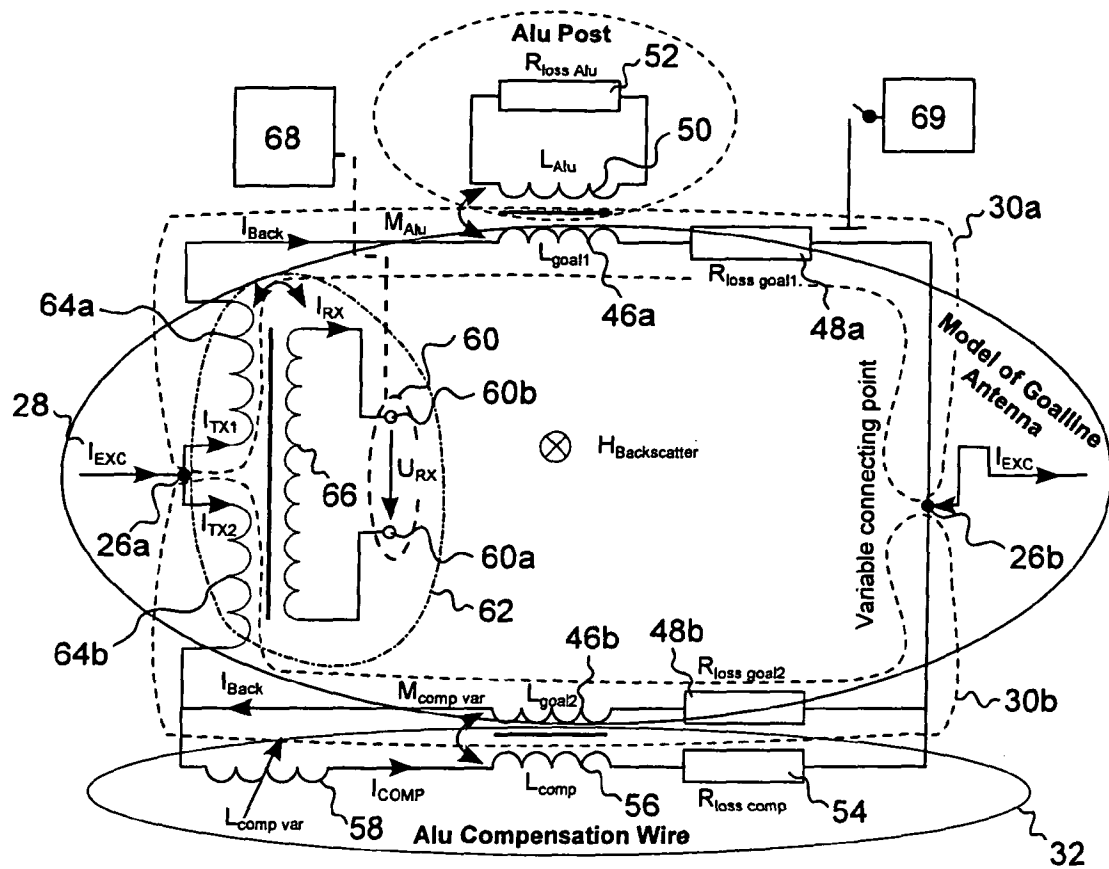


Fig. 7

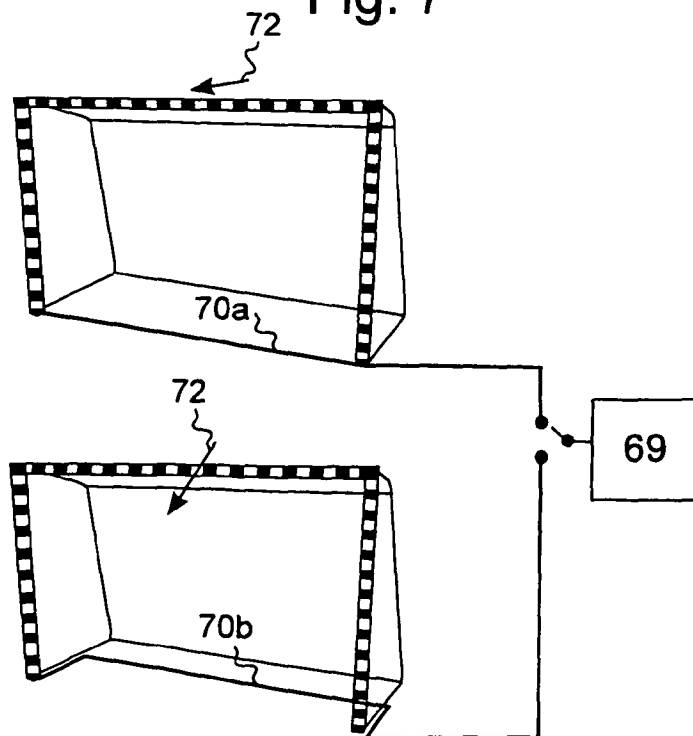


Fig. 8

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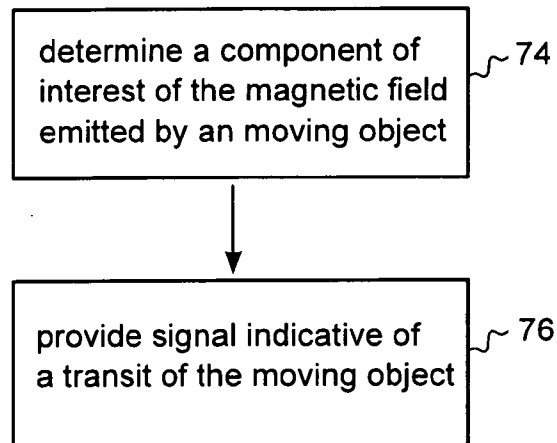


Fig. 9

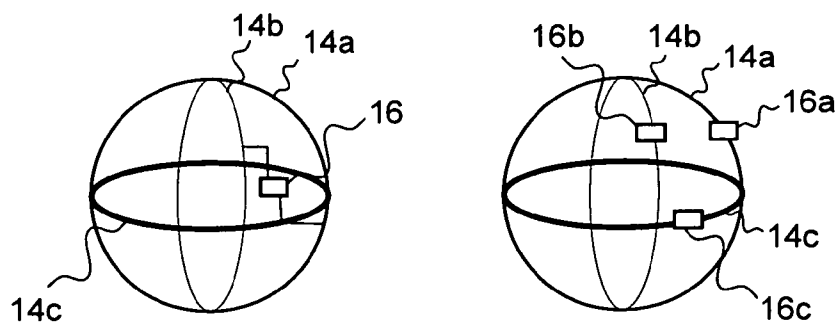


Fig. 10