(54) Title: INDOOR POSITIONING SYSTEM AND METHOD

(57) **Abstract:** An indoor positioning method, comprising: receiving, at an apparatus, radio signals from a first location; discriminating the radio signals, in order to estimate a bearing from the first location; and estimating, using the bearing and constraint information which is independent of the radio signals, the position of the apparatus.

RECEIVING RADIO SIGNALS   200

DISCRIMINATING RADIO SIGNALS   210

ESTIMATING A BEARING   220

ESTIMATING A POSITION   230

FIG. 3

TITLE

INDOOR POSITIONING SYSTEM AND METHOD

5   FIELD OF THE INVENTION

Embodiments of the present invention relate to positioning. In particular, they relate to a method, an apparatus, a module, a chipset or a computer program for positioning using radio signals.

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BACKGROUND TO THE INVENTION

There are a number of known techniques for determining the position of an apparatus using radio frequency signals. Some popular techniques relate to

15   use of the Global Positioning System (GPS), in which multiple satellites orbiting Earth transmit radio frequency signals that enable a GPS receiver to determine its position. However, GPS is often not very effective in determining an accurate position indoors.

20   Some non-GPS positioning techniques enable an apparatus to determine its position indoors. However, some of these techniques do not result in an accurate position being determined, and others are too complex for use simply in a portable apparatus. For example, the amount of processing power required to perform the technique may be impractical to provide in a portable

25   apparatus, which may need to perform concurrent functions.

BRIEF DESCRIPTION OF VARIOUS EMBODIMENTS OF THE INVENTION

According to various embodiments of the invention there is provided a

30   method, comprising receiving, at an apparatus radio signals from a first location; discriminating the radio signals, in order to estimate a bearing from

the first location; and estimating, using the bearing and constraint information that is independent of the radio signals, a position of the apparatus.

According to various embodiments of the invention there is provided an
5   apparatus, comprising: a receiver configured to receive radio signals from a first location; processing circuitry configured to discriminate the radio signals, in order to estimate a bearing from the first location, and configured to estimate, using the bearing and constraint information that is independent of the radio signals, a position of the apparatus.

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According to various embodiments of the invention there is provided an apparatus, comprising: means for receiving radio signals from a first location; means for discriminating the radio signals, in order to estimate a bearing from the first location; and means for estimating, using the bearing and constraint

15   information that is independent of the radio signals, a position of the apparatus.

According to various embodiments of the invention there is provided a module, comprising: processing circuitry configured to use complex samples

20   of further radio signals received from a first location by a receiver, in order to estimate a bearing from the first location, and configured to estimate, using the bearing and constraint information that is independent of the radio signals, a position of the receiver.

25   According to various embodiments of the invention there is provided a chipset, comprising: processing circuitry configured to use complex samples of further radio signals received from a first location by a receiver, in order to estimate a bearing from the first location, and configured to estimate, using the bearing and constraint information that is independent of the radio signals,

30   a position of the receiver.

According to various embodiments of the invention there is provided a computer program, comprising: instructions for using complex samples of further radio signals received from a first location by a receiver, in order to estimate a bearing from the first location; and instructions for estimating, using
5   the bearing and constraint information that is independent of the radio signals, a position of the receiver.

BRIEF DESCRIPTION OF THE DRAWINGS

10   For a better understanding of various embodiments of the present invention reference will now be made by way of example only to the accompanying drawings in which:

Fig. 1 illustrates an apparatus receiving radio signals from a transmitter;
15   Fig 2A is a schematic of a transmitter apparatus;
Fig. 2B is a schematic of a receiver apparatus;
Fig. 3 is a flow diagram of a method of estimating a position of the apparatus;
Fig. 4 illustrates a schematic for estimating the position of the apparatus;
Fig. 5 illustrates first and second bearings being used to position the
20   apparatus;
Fig. 6 illustrates possible positions of the apparatus on a bearing in a multi-floor environment;
Fig. 7 illustrates determining a position of the apparatus in a multi-floor environment; and
25   Fig. 8 illustrates determining a position when radio signals are reflected.

DETAILED DESCRIPTION OF VARIOUS EMBODIMENTS OF THE INVENTION

30   The Figures illustrate receiving, at an apparatus 10, radio signals 50 from a first location 80; discriminating the radio signals, in order to estimate a bearing 82 from the first location 80; and estimating, using the bearing 82 and

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constraint information 11, 17, 182 that is independent of the radio signals 50, a position of the apparatus 10.

Fig. 1 illustrates a person 92 (carrying a receiver apparatus 10) at a position
5   95 on a floor 100 of a building 94. The building 94 could be, for example, a shopping center or a conference center.

A transmitter 30 is positioned at a location 80 of the building 94. In the illustrated example, the location 80 is on the ceiling of the building 94 (i.e. the
10   overhead interior surface) but in other implementations the transmitter may be placed elsewhere such as on a wall.

The location 80 is directly above the point denoted with the reference numeral 70 on the floor 100 of the building. The transmitter 30 is for enabling a user of
15   an apparatus 10, such as the person 92, to determine his position 95, although that is not necessarily the only function provided by the transmitter 30. For example, the transmitter 30 may be part of a transceiver for providing wireless internet access to users of apparatuses 10, for example, via WLAN radio signals.
20

The position 95 of the person 92 is defined by specifying a position along a bearing 82 (illustrated in Fig 4) which runs from the location 80 of the transmitter 30 through the location 95 of the apparatus 10, The bearing 82 is defined by an elevation angle θ and an azimuth angle Φ.
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Fig. 2A schematically illustrates one example of the transmitter 30. The transmitter 30 comprises a controller 33, transmitter circuitry 34 and an antenna array 36 comprising a plurality of antenna elements 32A, 32B, 32C which transmit respective radio signals 50A, 50B, 50C.....
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The radio signals 50 may be transmitted periodically as beacons by the transmitter 30.

In the illustrated example, separate signals 50 are transmitted via the array 36 of antenna elements 32 in a time division multiplexed fashion. A switch 38 is used to connect each one of the antenna elements 32 to the transmitter

5   circuitry 34 one at a time, in a predefined order. The radio signals 50A, 50B, 50C from the different antenna elements 32A, 32B, 32C are therefore transmitted sequentially in different slots of a frame.

In the Figure only three different displaced antenna elements 32 are

10   illustrated, although in actual implementations more antenna elements 32 may be used. The working prototype uses 16 patch antenna elements distributed over the surface of a hemisphere. Three is the minimum number of radio signals required at the receiver apparatus 10 to be able to determine a bearing 82.

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In other embodiments, there may be a separate transmitter circuit 34 associated with each antenna element 32. In this embodiment, it may be possible to transmit one or more of the signals 50 in parallel.

20   Each signal 50 has a characteristic that enables it to be discriminated by the receiver apparatus 10. The characteristic may be a feature of the signal itself such as a code sequence that has been modulated onto a carrier wave or it may be a feature of the signal's position relative to the other signals such as its 'slot' number within a frame. In the latter case, all of the signals in the slots

25   of a frame may have the same or different code sequences.

The receiver apparatus 10 needs to obtain 'displacement information' from the received signals 50A, 50B, 50C that is dependent upon the relative displacements of the respective antenna elements 32A, 32B, 32C. In the

30   example described in detail below, the displacement information is phase information.

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In one embodiment, it may be possible to modulate a carrier wave using convolution codes, as in code division multiple access. Explicit displacement information may then be determined at a receiver apparatus 10 by correlating the expected code against the received signal 50.

One disadvantage of this approach is that the resolution required for the displacement information to be able to resolve relative spatial separation between the antenna elements 32 of a few centimeters would require a very high chip rate e.g. of the order 10GHz and a correspondingly large bandwidth and a correspondingly accurate clock.

One advantage of this approach is that knowledge of how the array 36 of antenna elements 32 transmits is not required at the receiver as the displacement information is determined from data encoded onto the carrier rather than from a property of the carrier itself.

Another simpler embodiment, modulates the carrier wave using I-Q modulation, also known as quadrature phase shift modulation. In this modulation technique, two orthogonal carrier waves (sine and cosine) are independently amplitude modulated to define a symbol. At the receiver apparatus 10, the amplitude of the two orthogonal carrier waves is detected as a complex sample and the closest matching symbol determined. It should be appreciated that an identical signal transmitted from different antenna elements will be received with different phases because of the inherent phase characteristics of the antenna elements 32 when transmitting in different directions and also because of the additional time of flight for a signal 50 from one antenna element to reach the receiver apparatus 10 compared to another signal 50. The inherent presence of this 'time of flight' information within the phases of the received signals 50 enables the received signals 50 to be processed, as described in more detail below, to determine the bearing 82 of the receiver apparatus 10 from the transmitter 30.

One advantage of this approach is that the resolution required for the displacement information to be able to resolve relative spatial separation between the antenna elements 32 of a few centimeters would require a carrier frequency of the order 10GHz but a much lower modulation rate may be used
5   and therefore correspondingly small bandwidth and slower clock can be used.

One disadvantage of this approach is that knowledge of how an antenna array 36 transmits is required at the receiver apparatus 10 as the inherent displacement information is determined from a property (phase) of the carrier
10   itself and antenna elements 32 typically transmit with different phase offsets at different angles. This knowledge may take the form of an array transfer function.

Fig. 1B illustrates a schematic of a receiver apparatus 10. The apparatus 10
15   may, for example, be a hand portable electronic device such as a mobile radiotelephone. The apparatus 10 comprises processing circuitry 12, a storage device 14, a receiver 16, a user input device 18 and a user output device 20.

20   The processing circuitry is used to discriminate between radio signals 50 received from a first location 80 by the receiver 16, estimate a bearing 82 from the first location 80; and estimate, using the bearing 82 and constraint information that is independent of the radio signals 50, a position of the apparatus 10.
25
The portable apparatus itself does not need to transmit to determine its position. Furthermore it alone may perform the processing necessary to determine a bearing 82 and to estimate, using the bearing and constraint information, the position of the apparatus 10 along the bearing 82.
30
The processing circuitry 12 may be any type of processing circuitry. For example, the processing circuitry 12 may be a programmable processor that

interprets computer program instructions 13 and processes data. Alternatively, the processing circuitry 12 may be, for example, programmable hardware with embedded firmware. The processing circuitry 12 may be a single integrated circuit or a set of integrated circuits (i.e. a chipset). The

5   processing circuitry 12 may also be a hardwired, application-specific integrated circuit (ASIC).

It will be appreciated by those skilled in the art that, for clarity, the processing circuitry is described as being a separate entity to the receiver. However, it

10   will be understood that the term processing circuitry may relate not only to a main processor of an apparatus, but also processing circuitry included in a dedicated receiver chipset, and even to a combination of processing circuitry included in a main processor and a dedicated receiver chipset.

15   A chipset for performing embodiments of the invention may be incorporated within a module. Such a module may be integrated within the apparatus 10, and/or may be separable from the apparatus 10.

The processing circuitry 12 is connected to receive an input from the receiver

20   16. The receiver 16 is configured to receive radio frequency signals. The radio signals may, for instance, have a transmission range of 100 meters or less. For example, the radio frequency signals may be 802.11 wireless local area network (WLAN) signals, Bluetooth signals, Ultra wideband (UWB) signals or Zigbee signals.

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The processing circuitry 12 is connected to write to and read from the storage device 14. The storage device 14 may be a single memory unit or a plurality of memory units.

30   The storage device 14 may store computer program instructions 13 that control the operation of the apparatus 10 when loaded into processing

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circuitry 12. The computer program instructions 13 may provide the logic and routines that enables the apparatus to perform the method illustrated in Fig 3.

The computer program instructions 13 may arrive at the apparatus 10 via an
5   electromagnetic carrier signal or be copied from a physical entity 21 such as a computer program product, a memory device or a record medium such as a CD-ROM or DVD.

The computer program instructions 13 provide: instructions for discriminating
10   210 between radio signals 50 received from a first location 80 by the receiver 16, in order to estimate 220 a bearing 82 from the first location 80; and instructions for estimating 230, using the bearing 82 and constraint information 11, 17, 182 that is independent of the radio signals 50, a position of the receiver 16.

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The processing circuitry 12 is connected to receive an input from the user input device 18. The processing circuitry 12 is also connected to provide an output to the user output device 20. The user output device 20 is for conveying information to a user and may be, for example, a display device.
20   The user input device 18 and the user output device 20 together form a user interface 22. The user interface 22 may be provided as a single unit, such as a touch screen display device.

Fig. 3 illustrates a method for estimating the position of the apparatus 10.
25   Various embodiments of the method of Fig. 2 will be described hereinafter in relation to Figs 4 to 8.

In the following it will be assumed that the respective radio signals 50A, 50B, 50C are sent in different slots of a TDMA frame and that the same code is
30   modulated onto the signals using IQ modulation, in this case Binary Phase Shift Key (BPSK) modulation as it is the most robust. It will be appreciated

that in other embodiments different types of signals may be used and different methods of discriminating the signals will be required.

5   At block 200 of the method of Fig. 3, the receiver 16 of the apparatus 10 receives radio signals 50 including first, second and third radio signals 50A, 50B, 50C.

At block 210, the processing circuitry 12 of the apparatus 10 discriminates between the respective radio signals 50 . In this example, this may be

10   achieved by identifying which slot in the TDMA frame the signal was received in. At least three respective radio signals 50A, 50B and 50C will need to be discriminated

The processing circuitry 12 obtains comparable complex samples (i.e.

15   samples that represent same time instant) for the three respective radio signals 50A, 50B, 50C.

In some embodiments of the invention, the transmitter 30 may transmit calibration data 15 in a radio signal to the apparatus 10 for storage in memory 14, before the transmission of the radio signals 50, to enable the processing

20   circuitry 12 of the apparatus 10 to discriminate between the radio signals 50. The calibration data 15 may, for example, be transmitted periodically as a beacon signal by the transmitter 30. In the described example, the calibration data 15 may include discrimination data that identifies the code used to modulate the signals, information about the TDMA frame, and possible

25   information identifying the IQ modulation used and antenna array calibration data that includes information that defines the transfer function of the antenna array 36.

The calibration data 15 may be encrypted. A key to decrypt the calibration

30   data 15 may be available from a remote server. For example, if the transmitter 30 is part of a transceiver for providing internet access, the decryption key may be obtainable from a remote server that is accessible via the transceiver.

In an embodiment where the apparatus 10 also functions as a mobile telephone, the decryption key may be obtainable from a remote server connected to a mobile telephone network. Alternatively, the calibration data 15 itself may be available from a remote server via a mobile telephone
5   network, rather than from the transmitter 30.

At block 220, the processing circuitry 12 estimates a bearing 82. One method of determining the bearing 82 is now described, but other methods are
10   possible.

Once comparable complex samples (i.e. samples that represent same time instant) from each antenna element 32 are obtained the array output vector y(n) (also called as snapshot) can be formed at by the processing circuitry 12.
15

$$\mathbf{y}(n) = \begin{bmatrix} x_1, & x_2, \ldots, x_M \end{bmatrix}^T, \tag{1}$$

Where x_i is the complex signal received from the ith TX antenna element 32, n is the index of the measurement and M is the number of TX elements 32 in
20   the array 36.

A Direction of Departure (DoD) can be estimated from the measured snapshots if the complex array transfer function $a(\varphi, \theta)$ of the TX array 36 is known, which it is from calibration data 15.
25

The simplest way to estimate putative DoDs is to use beamforming, i.e. calculate received power related to all possible DoDs. The well known formula for the conventional beamformer is

30   $$P_{BF}(\varphi, \theta) = \mathbf{a}^*(\varphi, \theta)\hat{\mathbf{R}}\mathbf{a}(\varphi, \theta), \tag{2}$$

Where,

$$\hat{R} = \frac{1}{N} \sum_{n=1}^{N} y(n) y^*(n)$$ is the sample estimate of the covariance matrix of the

received signals, $a(\varphi, \theta)$ is the array transfer function related to the DoD (φ, θ),

φ is the azimuth angle and θ is the elevation angle.

Once the output power of the beamformer $P_{BF}(\varphi, \theta)$ is calculated in all

possible DoDs the combination of azimuth and elevation angles with the

highest output power is selected to be the bearing 82.

The performance of the system depends on the properties of the TX array 36.

For example the array transfer functions $a(\varphi, \theta)$ related to different DoDs

should have as low correlation as possible for obtaining unambiguous results.

Correlation depends on the individual radiation patterns of the antenna

elements 32, inter element distances and array geometry. Also the number of

array elements 32 has an effect on performance. The more elements 32 the

array 36 has the more accurate the bearing estimation becomes. In minimum

there should be at least 3 antenna elements 32 in planar array configurations

but in practice 10 or more elements should provide good performance.

Next, at block 230 the processing circuitry 12 estimates a position of the

apparatus 10 using the bearing and constraint information.

In some embodiments of the invention, such as those illustrated in Figs. 4 and

5, the use of constraint information enables the processing circuitry 12 to

determine the location of the apparatus 10 along the estimated bearing 82.

The storage device 14 may store apparatus data 17 which indicates a vertical

displacement d from the ground floor 100 to the apparatus 10. The value for

the vertical displacement may or may not be input by the user. For instance,

the storage device 14 may be pre-loaded with a predetermined value for the

apparatus data 17 (e.g. 1.2 meters) or the apparatus data 17 may be received in a radio signal from the transmitter 30.

The storage device 14 may also store map data 19 which corresponds to a map of the building 94, and location data 11 which indicates the location of the transmitter 30 on the map. The map data 19 and/or location data 11 may be obtained from the transmitter 30. Alternatively, the map data and/or the location data 11 may be obtained from a remote server, either via the transmitter 30 (e.g. where the transmitter 30 is part of a transceiver which provides access to the internet) or via a mobile telephone network.

Referring now to Fig. 4, as the vertical displacement d from the ground floor 100 to the apparatus 10 is given by the apparatus data 17, and the vertical displacement z from the ground floor 100 to the location 80 of the transmitter 30 is given by the location data 11, the processing circuitry 12 may estimate the vertical displacement h=z-d from the position 95 of the apparatus 10 to the location 80 of the transmitter 30.

Fig. 4 also illustrates the bearing 82 from the location 80 of the transmitter 30 to the location 95 of the apparatus 10, which has been estimated by the processing circuitry 12 following reception of the radio signals 50. The bearing 82 is defined by an elevation angle θ and an azimuth angle Φ.

The processing circuitry 12 may estimate the position of the apparatus 10 relative to the location 80 of the transmitter 30 in coordinates using the bearing (elevation angle θ, azimuth angle Φ) and constraint information (vertical displacement h). The processing circuitry 12 may estimate the position of the apparatus 10 in Cartesian coordinates by converting the coordinates using trigonometric functions.

Once the processing circuitry 12 has estimated the position of the apparatus 10 relative to location 80 of the transmitter 30, it is able to estimate the

position of the apparatus 10 on the map because the location 80 of the transmitter 30 on the map is known from the location data 11. The processing circuitry 12 may control the user output device 20 to display the map and to indicate to the user the position of the apparatus 10 on the map.

Fig. 5 illustrates a building 94 having two transmitters 30, 130 located on the ceiling of the building 94 in this example. The two transmitters 30, 130 are of the same form as that of the transmitter 30 described in relation to in Fig 1. The first transmitter 30 is positioned at a location 80 on the ceiling, directly above the point denoted with the reference numeral 70 on a floor 100 of the building 94. The second transmitter 130 is positioned at a location 180 on the ceiling, directly above the point denoted with the reference numeral 170 on the floor 100. The separation of the transmitters 30, 130 is large in comparison with the separation of the antenna elements 32 or 132 with their respective arrays. .

In this embodiment, the apparatus 10 receives radio signals 50 from the first transmitter 30 and determines a bearing 82 of the apparatus 10 from the first transmitter 30 as described in relation to blocks 200, 210, 220 of Fig 3. The bearing 82.

The apparatus 10 also receives radio signals 150 from the second transmitter 130 and determines, as constraint information, a bearing 182 of the apparatus 10 from the first transmitter 30 using the method as described in relation to blocks 200, 210, 220 of Fig 3. The discrimination of the radio signals 150A, 150B, 150C at block 210 and the estimation of the bearing 182 will require second calibration data including, for example, the transfer function of the antenna array used by the second transmitter 130.

The apparatus 10 may receive second calibration data from the second transmitter 130.

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Once the bearings 82 and 182 have been estimated, the processing circuitry 12 may estimate that the apparatus 10 is situated at a position along bearing 82 as defined by the constraining bearing 182. It may be that processing circuitry 12 estimates an area that the apparatus 10 is likely to be positioned 5   in if the accuracy of the bearings 82, 182 is such that the processing circuitry 12 is not able to pinpoint the position of the apparatus 10 with a high degree of precision. Once the position of the apparatus 10 has been estimated, the processing circuitry 12 may control the user output device 20 to convey the estimated position to the user.

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Fig. 6 illustrates a transmitter 30 located on a ceiling 140 of a building 94. In this particular example, the building 94 has four floors 100, 110, 120, 130. A bearing 82 from the location 80 of the transmitter 30 has been estimated using radio signals 50 in the manner described above in relation to Figs 1 and 15   3.

Having estimated the bearing 82, the processing circuitry 12 determines that there are four possible positions 91, 92, 93, 95 of the apparatus 10. In this example, it is assumed that the radio signals 50 are able to penetrate the 20   upper three floors 110, 120 and 130 such that it is possible that the user is positioned on any of the floors 100, 110, 120 and 130. However, it may be that the map data 19 stored in the storage device 14 indicates to the processing circuitry 12 that radio signals from the transmitter 30 do not reach certain floors, for example, the ground floor 100. This enables the processing 25   circuitry 12 to discount the position 93 adjacent the ground floor 100 as a possible position of the user.

In order to determine the position of the apparatus 10 in relation to the estimated bearing 82, the processing circuitry 12 may control the user output 30   device 20 to display a query asking the user which floor he is on before his position is estimated. The processing circuitry 12 is able to compare the information input by the user with the map data 19 to determine which floor of

the building the user is situated on. For example, the user may indicate that he can see a particular shop on the floor that he is on. The processing circuitry 12 may then compare this input information with the map data 19 to determine which floor the user is on. In the example illustrated in Fig. 6, the

5   user indicates that he is situated on the first floor 110. In this embodiment, therefore, the user provides "constraint information" which enables his position to be determined.

Once the processing circuitry 12 has determined that the user is on the first

10   floor 110, it is able to estimate the position of the apparatus 10 using the same techniques as those mentioned in relation to Fig. 4. In the case illustrated in Fig. 6, the processing circuitry 12 is able to estimate the vertical displacement from the apparatus 10 to the transmitter 30 by using the known displacement from the first floor 110 of the building to the ceiling 140 (given by

15   the location data 11 stored in the storage device 14), and by using the vertical displacement from the first floor 110 to the apparatus 10 (given by the apparatus data 17).

In the example illustrated in Fig 7, the radio signals 50 are assumed or known

20   not to penetrate each floor 110, 120, 130 of the building. The processing circuitry 12 of the apparatus 10 may determine a bearing from the location 80 of the transmitter 30 on the ceiling 140 of the building 94 to the apparatus 10 using the techniques described in relation to Figs 1 and 3.

25   The location data 11 stored in the storage device 14 may include data which relates particular elevation angles with certain floors of the building 94. For example, if a bearing having an elevation angle from 0 to α is estimated by the processing circuitry 12, it indicates that the apparatus 10 is positioned on the top floor 130. A bearing having an elevation angle from α to β indicates that

30   the apparatus 10 is on the second floor 120. A bearing having an elevation angle from β to α indicates that the apparatus 10 is on the first floor 110. A

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bearing having an elevation angle from α to λ indicates that the apparatus is on the ground floor 100.

The processing circuitry 12 compares the elevation angle of the estimated bearing with the location data 11, and estimates which floor the apparatus 10 is situated on, thus estimating a position of the apparatus 10. The processing circuitry 12 then controls the user output device 20 to convey this information to the user. In this example, a position of the apparatus 10 is estimated by using an estimated bearing and constraint information. "Constraint information" is provided by the portion of the location data 11 that that relates particular angles of elevation to particular floors of the building.

Fig. 8 illustrates a situation where the user is positioned on the second floor 120 and the radio signals 50 transmitted by the transmitter 30 are reflected by the second floor 120. For ease of explanation, the radio signals 50 are shown following a common path 55, 56 from the transmitter 30 to the apparatus 10.

If the processing circuitry 12 estimates a bearing from the location 80 of the transmitter 30 using the techniques described above in relation to Figs 1 and 3, the estimated bearing will not take into account the reflection of the radio signals from the second floor 120 and will therefore follow the solid line 55 and the dotted line 57. However, it can be seen from Fig. 8 that the apparatus 10 is not positioned on this bearing.

In embodiments of the invention illustrated the example illustrated in Fig. 8, the processing circuitry 12 may be configured to determine whether the line of sight between the apparatus 10 and the transmitter 30 is blocked by determining if a reflection of the received radio signals 50 has occurred. This enables the processing circuitry 12 to determine whether an estimation of the bearing from the location 80 of the transmitter 30 to the apparatus 10 is likely to be accurate.

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When the radio signals 50 are reflected from a dielectric surface, the polarization of the signals 50 may change. The apparatus 10 may detect this change in polarization to determine whether a signal has been reflected, and to determine whether a correction to an estimated bearing is required.

Another way of determining if a reflection has occurred might be to determine whether the received signal strength intensity (RSSI) of one or more of the radio signals 50 is below a threshold. If the RSSI is below the threshold, the signal(s) is/are assumed to have been reflected.

Reference numeral 97 denotes the position that the processing circuitry 12 would estimate the apparatus 10 to be at, if it did not take into consideration that a reflection of the radio signals 50 had occurred. In the example illustrated in Fig. 8, the incorrect position 97 is separated in both a vertical sense and a horizontal sense from the location 80 of the transmitter 30. A distance r separates the incorrect position 97 from the location 80 of the transmitter 30 in the horizontal sense. The correct position 95 is separated from the location 80 of the transmitter 30 in a horizontal sense by a distance r'. The transmitter 30 and the second floor 120 are separated in a vertical sense by a distance h. The position of the apparatus 10 given by the apparatus data 17 is a vertical displacement m from the second floor 120. Using trigonometric identities, it can be shown that:

$$r' = \frac{h+m}{h-m} r \qquad (1)$$

The processing circuitry 12 may estimate r by using radio signals transmitted by the transmitter 30, as described in relation to Figs 1, 3 and 4. An assumed value of m is given by the apparatus data 17 (e.g. 1.2 meters). The vertical distance h may be found using the map data 19 and the location data 11, because the location data 11 provides the location of the transmitter 30 on the map.

Using these values of r, m and h as inputs to equation (1), the processing
circuitry 12 may estimate the position r' of the apparatus 10 relative to the
transmitter 30. As the location data 11 indicates the location 80 of the

5   transmitter 30 on the map stored in the storage device 14, the processing
circuitry 12 is able to determine the location 95 of the apparatus 10 on the
map and may control the user output device 18 to convey the position 95 of
the apparatus 10 on the map to the user.

10   Another method of determining the distance r', other than by directly using
equation (1), would be to determine the point at which the bearing 55, 57 has
a downward displacement of m from the second floor 120 (i.e. the floor that
the bearing 55, 57 intersects). This intersection is denoted by reference
numeral 99 on Fig. 8.

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It has been demonstrated that, in embodiments of the invention as described
above in relation to Figs 2 to 8, an apparatus 10 may estimate its position
without having to transmit radio signals to a receiver located in the building
94. This is particularly advantageous because it is possible for the apparatus

20   10 to remain anonymous from the radio equipment of the building 94.

The blocks illustrated in the Fig 3 may represent steps in a method and/or
sections of code in the computer program 13. The illustration of a particular
order to the blocks does not necessarily imply that there is a required or

25   preferred order for the blocks and the order and arrangement of the block may
be varied.

Although embodiments of the present invention have been described in the
preceding paragraphs with reference to various examples, it should be

30   appreciated that modifications to the examples given can be made without
departing from the scope of the invention as claimed. For example, the

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apparatus 10 may not function as a mobile telephone. It may, for example, be a portable music player having a receiver for receiving radio signals.

Various examples of constraint information have been given in the preceding paragraphs, but the term "constraint information" it is not intended to be limited to these examples.

Features described in the preceding description may be used in combinations other than the combinations explicitly described.

Whilst endeavoring in the foregoing specification to draw attention to those features of the invention believed to be of particular importance it should be understood that the Applicant claims protection in respect of any patentable feature or combination of features hereinbefore referred to and/or shown in the drawings whether or not particular emphasis has been placed thereon.

I/we claim:

CLAIMS

1. A method, comprising:
   receiving, at an apparatus, radio signals from a first location;
   discriminating the radio signals, in order to estimate a bearing from the first location; and
   estimating, using the bearing and constraint information that is independent of the radio signals, a position of the apparatus.

2. A method as claimed in claim 1, further comprising: obtaining the constraint information by receiving further radio signals from a second location; discriminating the further radio signals in order to estimate a further bearing from the second location; and estimating, using the bearing and, as constraint information, the further bearing, a position of the apparatus.

3. A method as claimed in claim 1, wherein the constraint information relates to a displacement associated with the apparatus.

4. A method as claimed in claim 3, wherein the displacement is a vertical displacement.

5. A method as claimed in claim 3 or 4, wherein the constraint information is received in a radio signal other than the received radio signals.

6. A method as claimed in claim 3 or 4, wherein the constraint information is input by a user.

7. A method as claimed in claim 3 or 4, wherein the constraint information is received from a remote server.

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8. A method as claimed in any of the preceding claims, further comprising receiving data to enable the received radio signals to be discriminated from one another.

5   9. A method as claimed in claim 8, wherein the data is received from the first location.

10. A method as claimed in claim 8, wherein the data is received from a remote server.

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11. A method as claimed in any of the preceding claims, wherein the received radio signals are transmitted by respective antenna elements of an antenna array and complex samples of the received radio signals are used to estimate the bearing from the first location.

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12. A method as claimed in claim 11, wherein a transfer function for the antenna array is used to estimate the bearing from the first location.

13. A method as claimed in any of the preceding claims, further comprising
20   determining whether a line of sight between the apparatus and the first location is blocked, and estimating the position of the apparatus differently in dependence upon the determination.

14. A method as claimed in any of the preceding claims, wherein a position
25   of the first location is known on a map, and estimating the position of the apparatus includes locating the apparatus relative to the first location using the estimated bearing.

15. A method as claimed in any of the preceding claims, wherein the
30   received radio signals are beacon signals.

16. A method as claimed in any of the preceding claims, wherein the apparatus is hand portable and the discrimination of the signals and the estimation of the position of the hand portable apparatus occurs only at the hand portable apparatus.

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17. An apparatus, comprising:

a receiver configured to receive radio signals from a first location;

processing circuitry configured to discriminate the radio signals, in order to estimate a bearing from the first location, and configured to

10   estimate, using the bearing and constraint information that is independent of the radio signals, a position of the apparatus.

18. An apparatus as claimed in claim 17, wherein the receiver is configured to receive the constraint information by receiving further radio signals

15   from a second location; and the processing circuitry is configured to discriminate the further radio signals, in order to estimate a further bearing from the second location, and to estimate, using the bearing and, as constraint information, the further bearing, a position of the apparatus.

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19. An apparatus, comprising:

means for receiving radio signals from a first location;

means for discriminating the radio signals, in order to estimate a bearing from the first location; and

25   means for estimating, using the bearing and constraint information that is independent of the radio signals, a position of the apparatus.

20. An apparatus as claimed in claim 19, wherein the means for receiving is for receiving the constraint information by receiving further radio

30   signals from a second location; the means for discriminating is for discriminating the further radio signals, in order to estimate a further bearing from the second location; and the means for estimating is for

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using the bearing and, as constraint information, the further bearing to estimate a position of the apparatus.

21. A system comprising: a transmitter comprising an array of antenna elements configured to transmit the received radio signals, and an apparatus as claimed in claim 17 or 19.

22. A system comprising: a first transmitter comprising an array of antenna elements configured to transmit the received radio signals, a second transmitter comprising an array of antenna elements configured to transmit the received further radio signals, and an apparatus as claimed in claim 18 or 20.

23. A module, comprising:
   processing circuitry configured to use complex samples of radio signals received from a first location by a receiver, in order to estimate a bearing of the receiver from the first location, and configured to estimate, using the bearing and constraint information that is independent of the received radio signals, a position of the receiver.

24. A module as claimed in claim 23, wherein processing circuitry is configured to use complex samples of further radio signals received from a second location by the receiver, in order to estimate a further bearing of the receiver from the second location, and is configured to estimate, using the bearing and, as constraint information, the further bearing, a position of the receiver.

25. A chipset, comprising:
   processing circuitry configured to use complex samples of radio signals received from a first location by a receiver, in order to estimate a bearing of the receiver from the first location, and configured to

25

estimate, using the bearing and constraint information that is independent of the received radio signals, a position of the receiver.

26. A chipset as claimed in claim 25, wherein processing circuitry is configured to use complex samples of further radio signals received from a second location by the receiver, in order to estimate a further bearing of the receiver from the second location, and is configured to estimate, using the bearing and, as constraint information, the further bearing, a position of the receiver.

27. A computer program, comprising:
instructions for using complex samples of radio signals received from a first location by a receiver, in order to estimate a bearing from the first location; and
instructions for estimating, using the bearing and constraint information that is independent of the radio signals, a position of the receiver.

28. A computer program module as claimed in claim 27, further comprising instructions for using complex samples of further radio signals received from a second location, in order to estimate a bearing from the second location, and instructions for estimating, using the bearing and the further bearing, a position of the receiver.

29. A tangible computer-readable storage medium comprising a computer program as claimed in claim 27 or 28.

AMENDED CLAIMS
received by the International Bureau on 26 January 2009 (26.01.2009)

1. A method, comprising:

   receiving, at an apparatus, first and second radio signals from a first
   location;

   discriminating the first and second radio signals, in order to estimate a
   bearing from the first location; and

   estimating, using the bearing, the first location and constraint
   information that is independent of the received first and second radio
   signals, a position of the apparatus.

2. A method as claimed in claim 1, further comprising: obtaining the
   constraint information by receiving third and fourth radio signals from a
   second location; discriminating the third and fourth radio signals in
   order to estimate a further bearing; and estimating, using the bearing
   and the further bearing, a position of the apparatus.

3. A method as claimed in claim 1, wherein the constraint information
   relates to a displacement associated with the apparatus.

4. A method as claimed in claim 3, wherein the displacement is a vertical
   displacement.

5. A method as claimed in claim 3 or 4, wherein the constraint information
   is received in a radio signal other than the first and second radio
   signals.

6. A method as claimed in claim 3 or 4, wherein the constraint information
   is input by a user.

7. A method as claimed in claim 3 or 4, wherein the constraint information
   received from a remote server.

AMENDED SHEET (ARTICLE 19)

8. A method as claimed in any of the preceding claims, further comprising receiving data to enable the first and second radio signals to be discriminated from one another.

9. A method as claimed in claim 8, wherein the data is received from the first location.

10. A method as claimed in claim 8, wherein the data is received from a remote server.

11. A method as claimed in any of the preceding claims, wherein the first radio signal is transmitted by a first antenna element and the second radio signal is transmitted by a second antenna element, and a relative displacement between the first and second antenna elements is used to estimate the bearing from the first location.

12. A method as claimed in any of the preceding claims, wherein a relative difference time of reception between the received first and second radio signals is used to estimate the bearing from the first location.

13. A method as claimed in any of the preceding claims, further comprising determining whether a line of sight between the apparatus and the first location is blocked, and estimating the position of the apparatus differently in dependence upon the determination.

14. A method as claimed in any of the preceding claims, wherein a position of the first location is known on a map, and estimating the position of the apparatus includes locating the apparatus relative to the first location using the estimated bearing.

AMENDED SHEET (ARTICLE 19)

15. A method as claimed in any of the preceding claims, wherein the first and second radio signals are beacon signals.

16. A method as claimed in any of the preceding claims, wherein the apparatus is hand portable and the discrimination of the signals and the estimation of the position of the hand portable apparatus occurs at the hand portable apparatus.

17. An apparatus, comprising:

a receiver configured to receive first and second radio signals from a first location;

processing circuitry configured to discriminate the first and second radio signals, in order to estimate a bearing from the first location, and configured to estimate, using the bearing, the first location and constraint information that is independent of the received first and second radio signals, a position of the apparatus.

18. An apparatus as claimed in claim 17, wherein the receiver is configured to receive the constraint information by receiving third and fourth radio signals from a second location; and the processing circuitry is configured to discriminate the third and fourth radio signals, in order to estimate a further bearing from the second location, and to estimate, using the bearing and the further bearing, a position of the apparatus.

19. An apparatus as claimed in claim 17, where the constraint information relates to a displacement associated with the apparatus.

20. An apparatus as claimed in claim 19, wherein the displacement is a vertical displacement.

21. An apparatus, comprising:

means for receiving first and second radio signals from a first location;

means for discriminating the first and second radio signals, in order to estimate a bearing from the first location; and

means for estimating, using the bearing, the first location and constraint information that is independent of the received first and second radio signals, a position of the apparatus.

22. An apparatus as claimed in claim 21, wherein the means for receiving is for receiving the constraint information by receiving third and fourth radio signals from a second location; the means for discriminating is for discriminating the third and fourth signals, in order to estimate a further bearing from the second location; and the means for estimating is for using the bearing and the further bearing to estimate a position of the apparatus.

23. A system comprising: a transmitter configured to transmit first and second radio signals, and an apparatus as claimed in any of claims 17 to 22.

24. A system comprising: a first transmitter configured to transmit first and second radio signals, a second transmitter configured to transmit third and fourth radio signals, and an apparatus as claimed in claim 18 or 22.

25. A module, comprising:

processing circuitry configured to use a time difference between arrival of a first radio signal and a second radio signal received from a first location by a receiver, in order to estimate a bearing from the first location, and configured to estimate, using the bearing, the first location and constraint information that is independent of the received first and second radio signals, a position of the receiver.

26. A module as claimed in claim 25, wherein processing circuitry is configured to use a time difference between arrival of a third radio signal and a fourth radio signal received from a second location by a receiver, in order to estimate a bearing from the second location, and is configured to estimate, using the bearing and the further bearing, a position of the receiver.

27. A chipset, comprising:

processing circuitry configured to use a time difference between arrival of a first radio signal and a second radio signal received from a first location by a receiver, in order to estimate a bearing from the first location, and configured to estimate, using the bearing, the first location and constraint information that is independent of the received first and second radio signals, a position of the receiver.

28. A chipset as claimed in claim 27, wherein processing circuitry is configured to use a time difference between arrival of a third radio signal and a fourth radio signal received from a second location by a receiver, in order to estimate a bearing from the second location, and is configured to estimate, using the bearing and the further bearing, a position of the receiver.

29. A computer program, comprising:

instructions for using a time difference between arrival of a first radio signal and a second radio signal received from a first location by a receiver, in order to estimate a bearing from the first location; and instructions for estimating, using the bearing, the first location and constraint information that is independent of the received first and second radio signals, a position of the receiver.

30. A computer program module as claimed in claim 29, further comprising instructions for using a time difference between arrival of a third radio

AMENDED SHEET (ARTICLE 19)

signal and a fourth radio signal received from a second location by a receiver, in order to estimate a bearing from the second location, and instructions for estimating, using the bearing and the further bearing, a position of the receiver.

31. A computer program as claimed in claim 29, where the constraint information relates to a displacement associated with the receiver.

32. A computer program as claimed in claim 31, wherein the displacement is a vertical displacement.

33. A computer-readable storage medium comprising a computer program as claimed in any of claims 29 to 32.
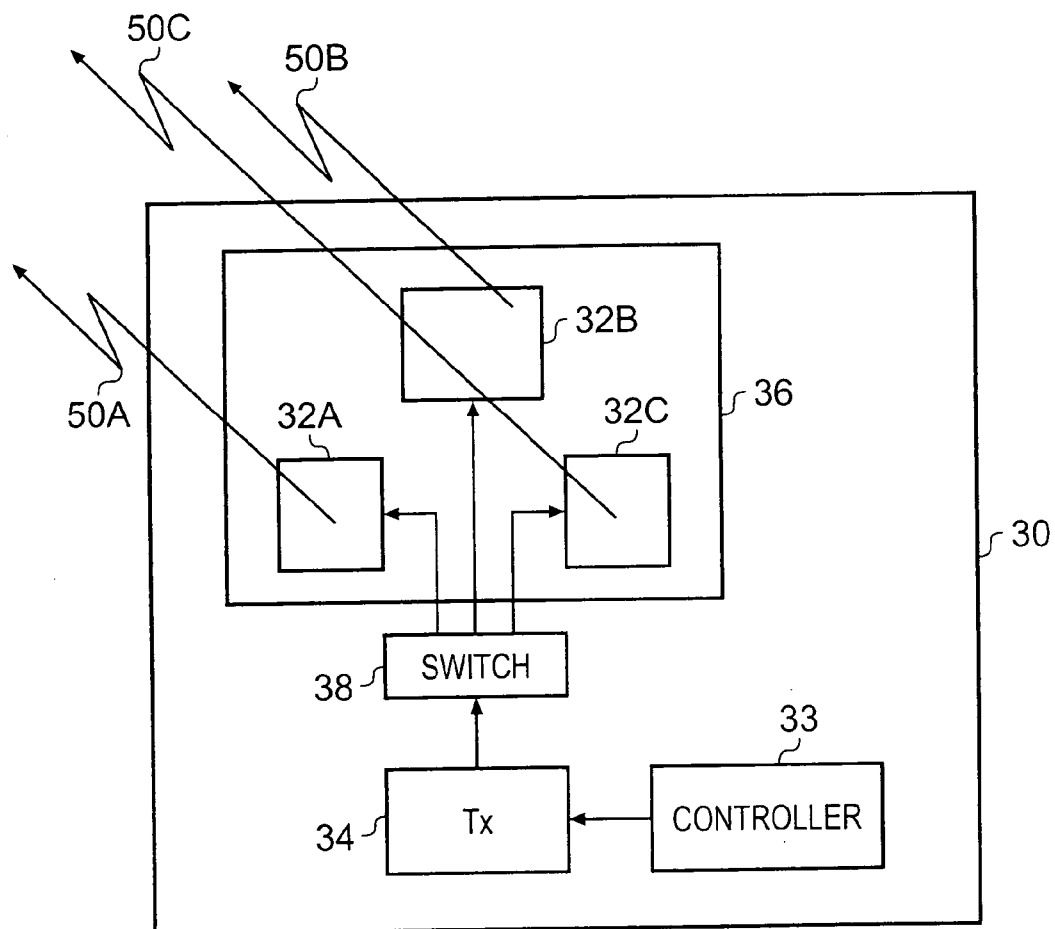
AMENDED SHEET (ARTICLE 19)
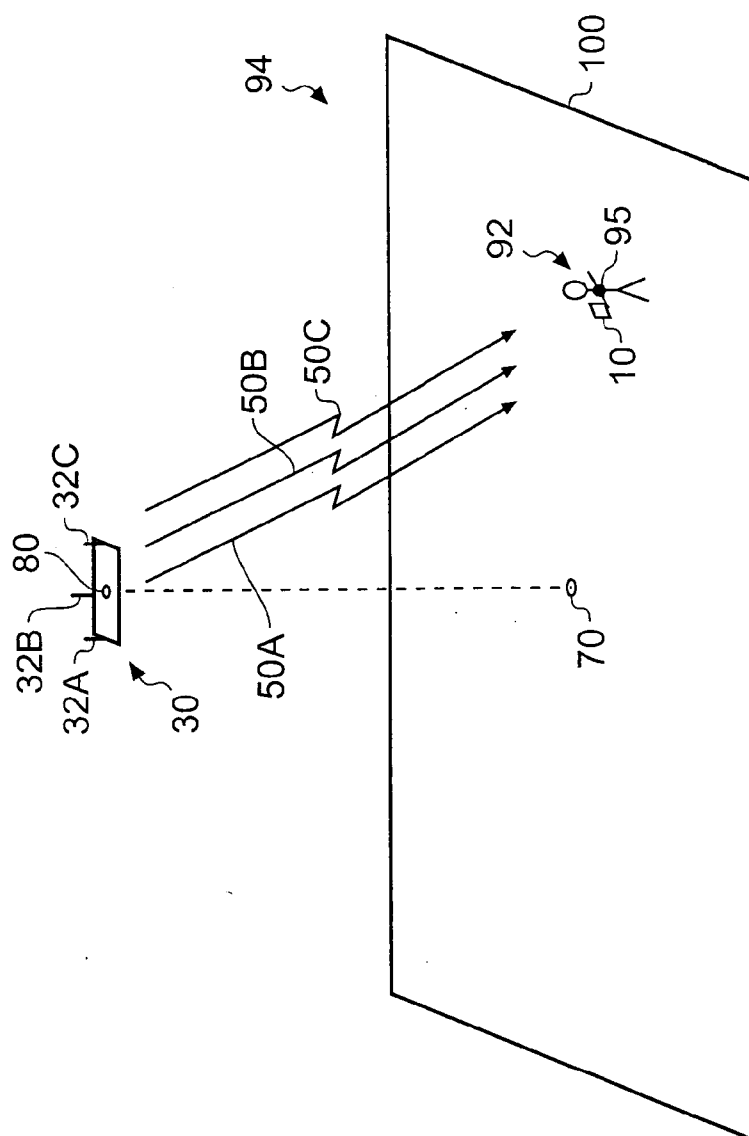
FIG. 1

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FIG. 2A

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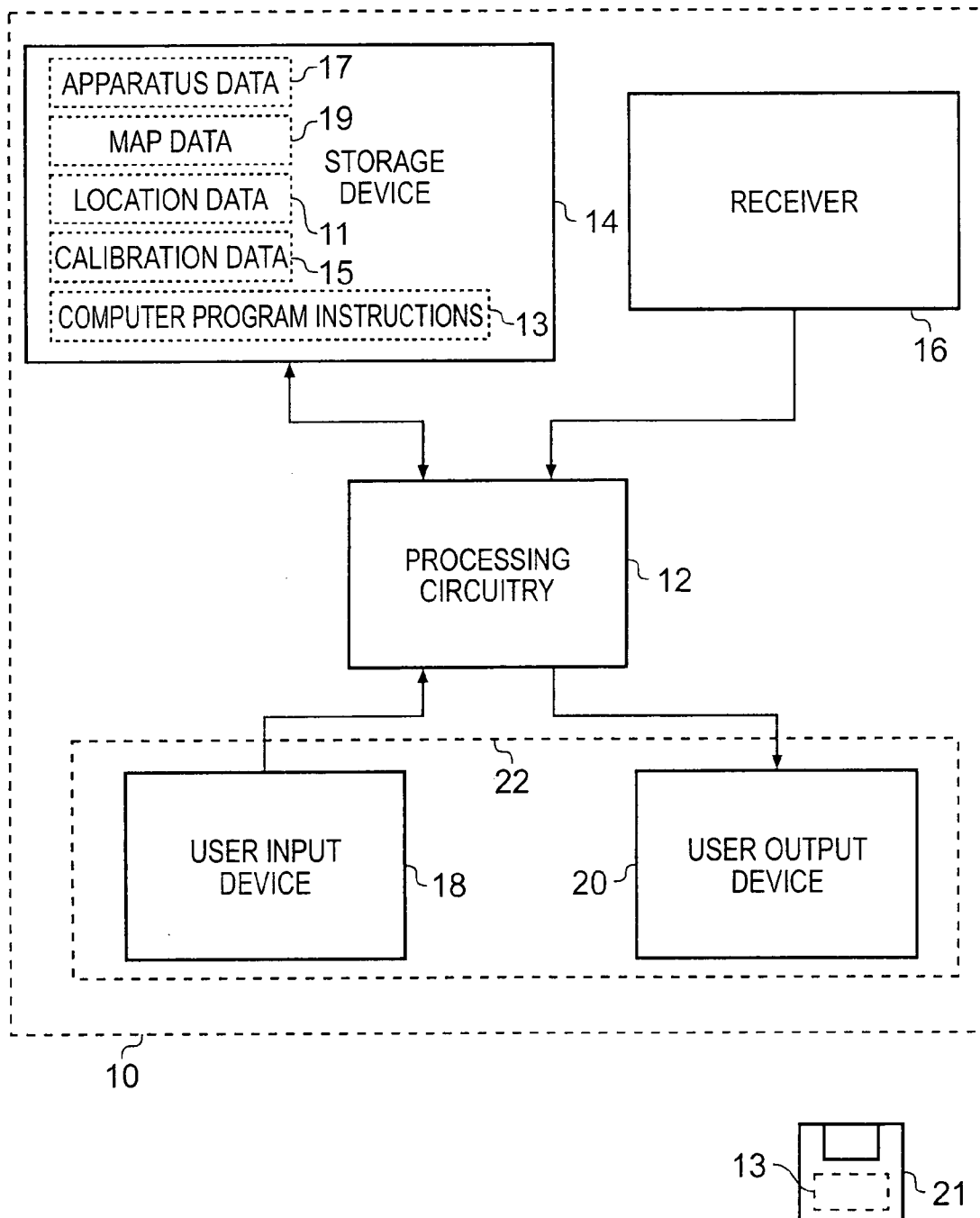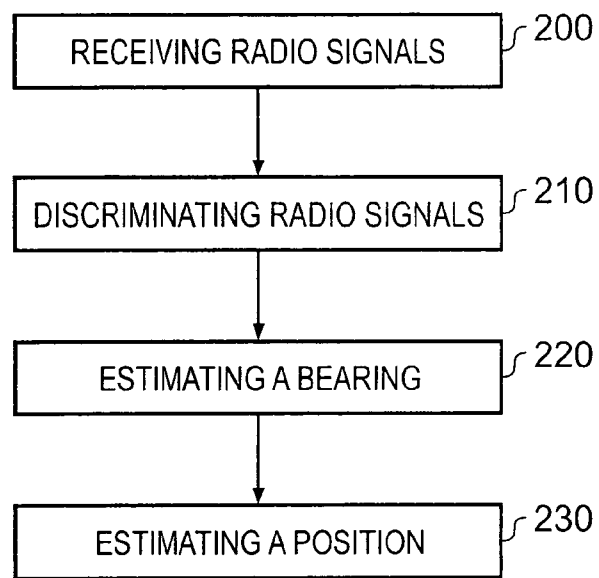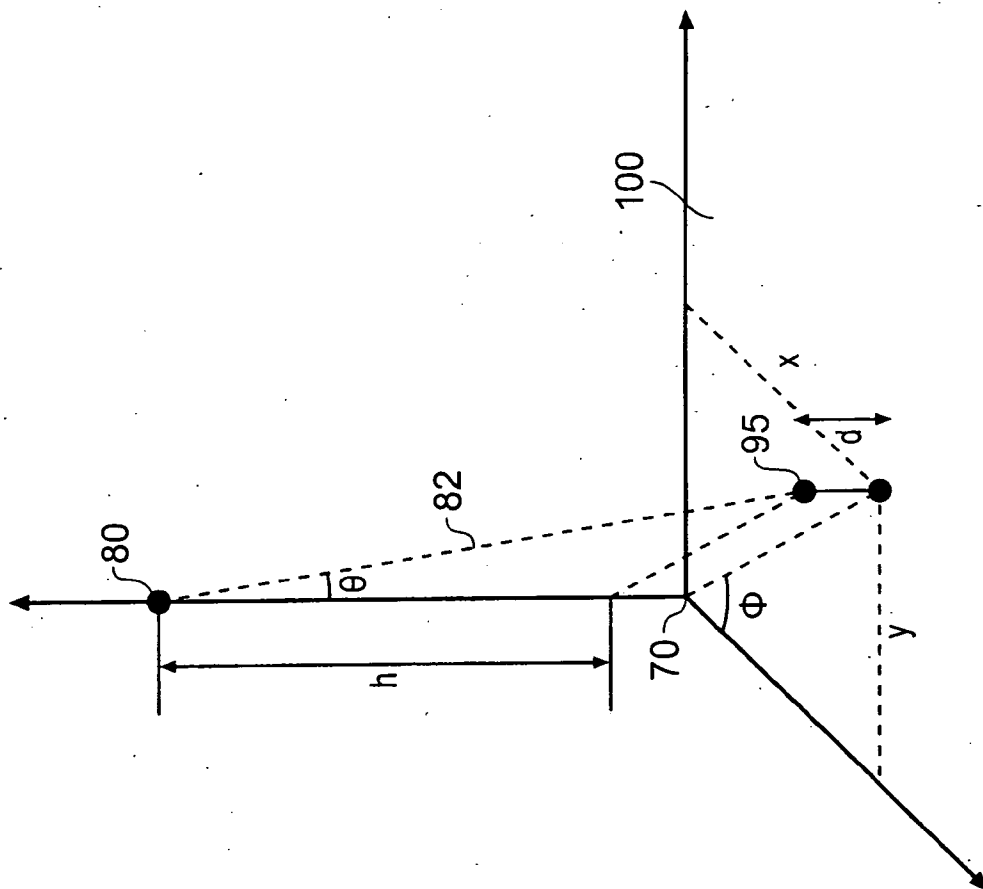FIG. 2B

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FIG. 3

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FIG. 4

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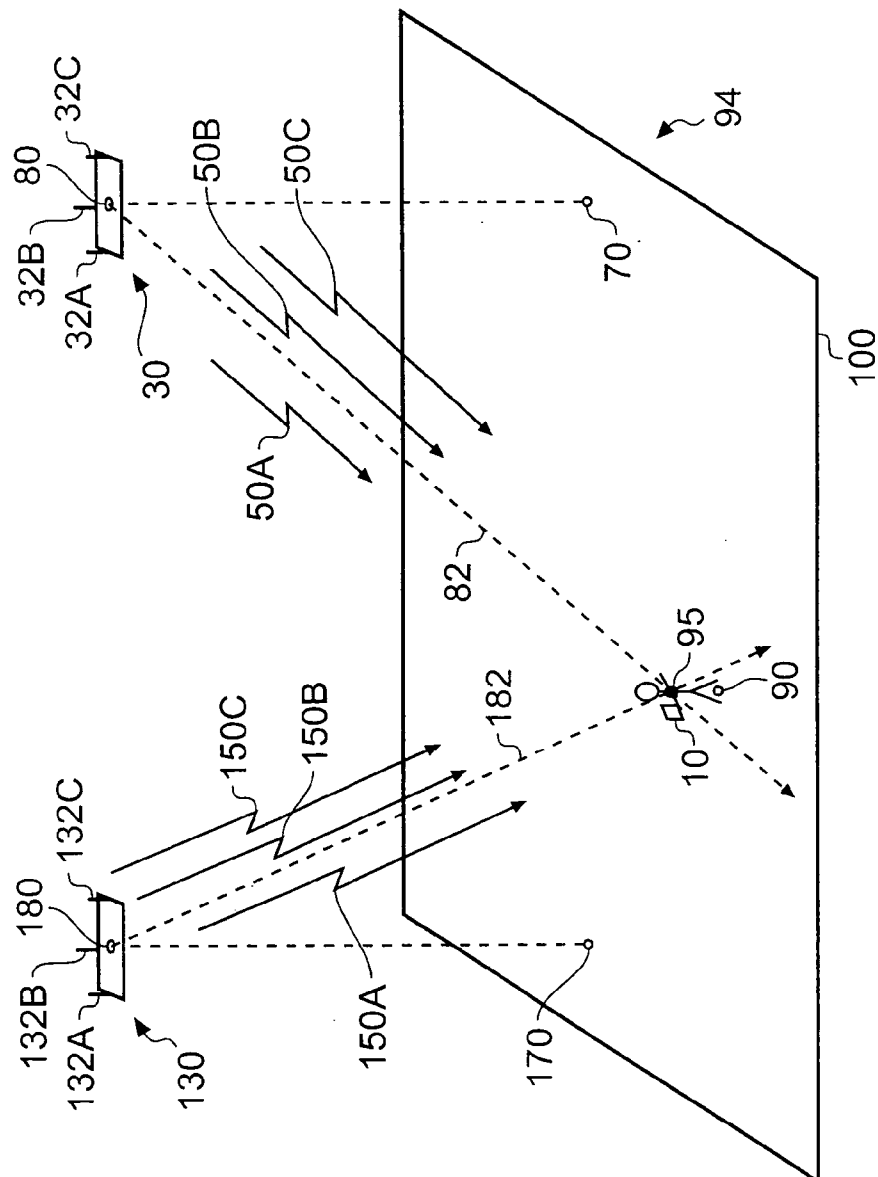
FIG. 5
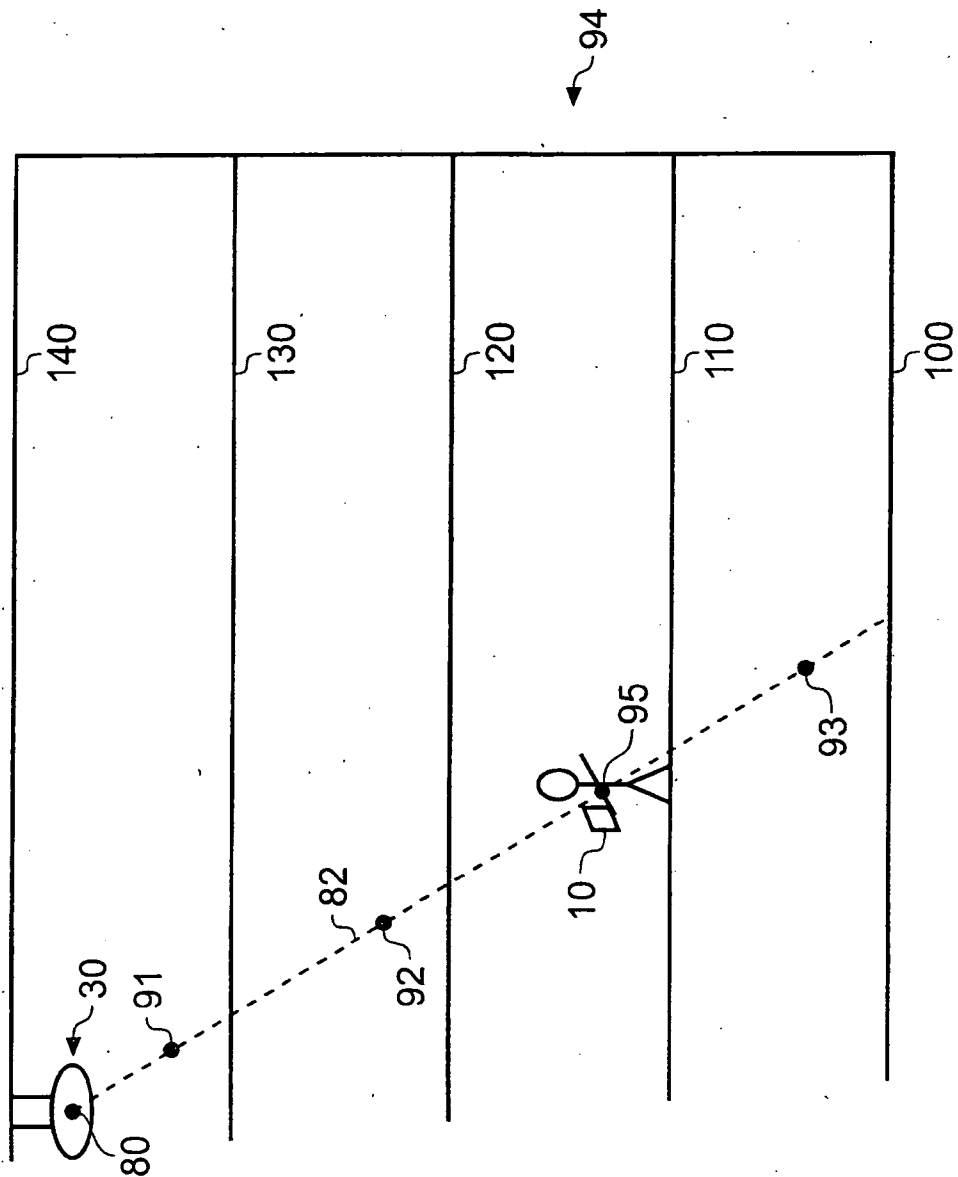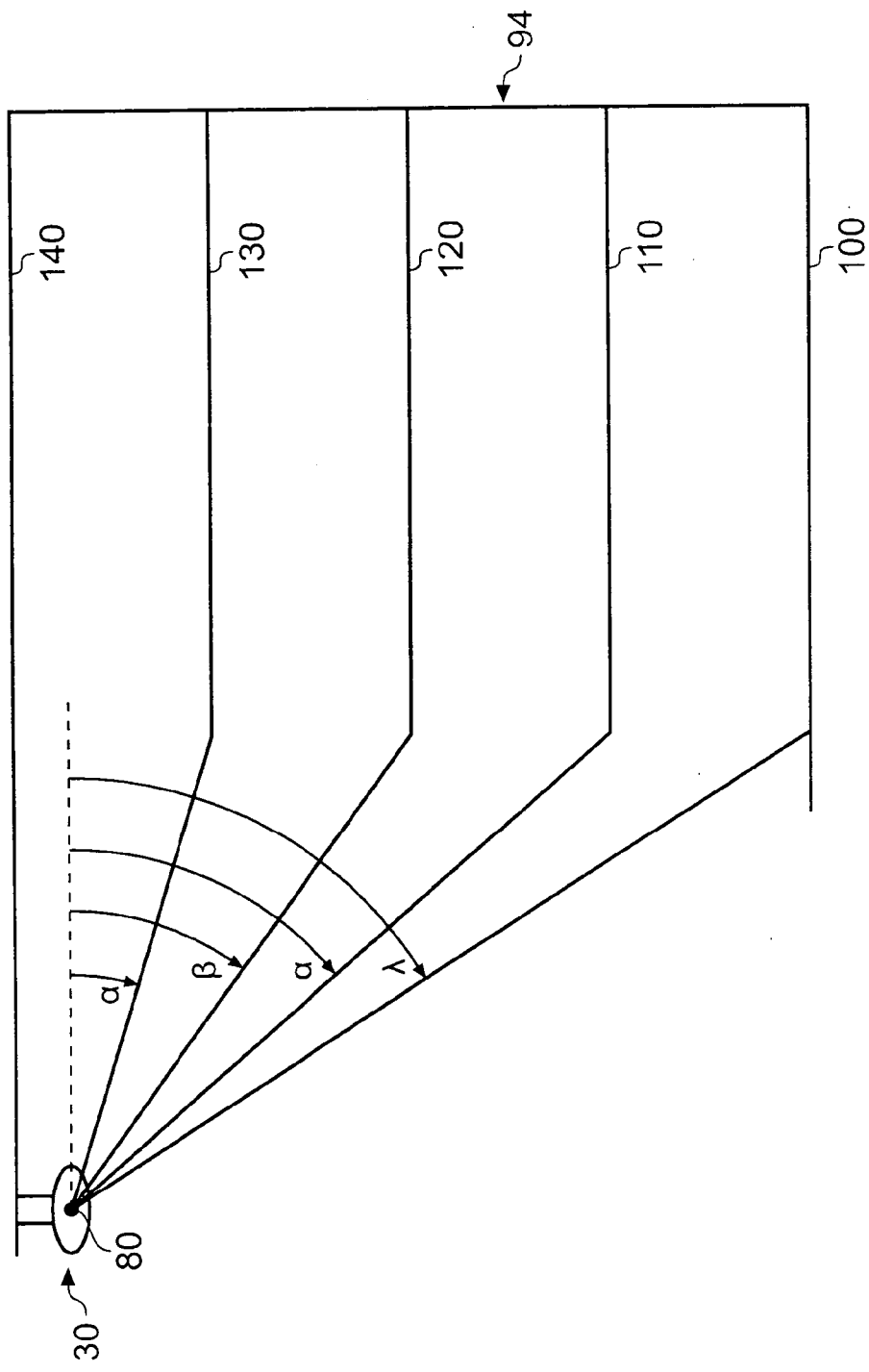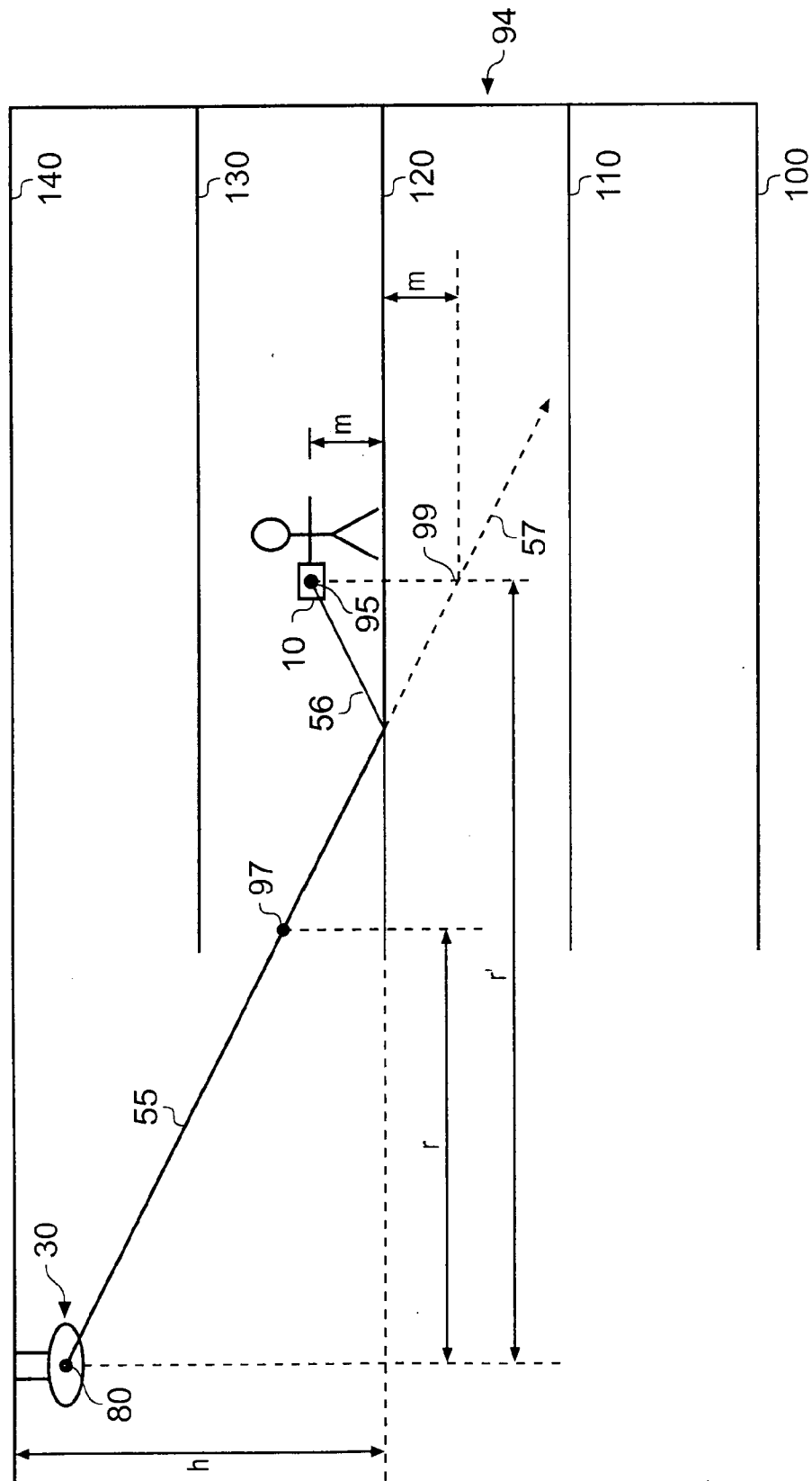
FIG. 6

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FIG. 7

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FIG. 8

INTERNATIONAL SEARCH REPORT

A. CLASSIFICATION OF SUBJECT MATTER
INV. G01S5/02   H04Q7/38

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
G01S H04Q

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 2004/162084 A1 (WANG YI-HSIU [US]) 19 August 2004 (2004-08-19) abstract figures 1,2,3a,3b paragraphs [0037] - [0050] claims 1-13	1-13, 15-29
X	US 2005/135292 A1 (GRAUMANN DAVID L [US]) 23 June 2005 (2005-06-23) abstract figure 2 paragraphs [0012] - [0029] claims 1-15	1-10, 13-20, 23-29

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[X] Further documents are listed in the continuation of Box C.   [X] See patent family annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
6 August 2008	14/08/2008

Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31–70) 340–2040, Tx: 31 651 epo nl, Fax: (+31–70) 340–3016	Esbri, Oriol

Form PCT/ISA/210 (second sheet) (April 2005)

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2002/167417 A1 (WELLES KENNETH BRAKELEY [US] ET AL WELLES II KENNETH BRAKELEY [US] ET) 14 November 2002 (2002-11-14) abstract figures 1,7,11,14-16 paragraphs [0003] - [0011] paragraphs [0045], [0049] - [0055]	1,17,19, 21,22
A	US 2002/122003 A1 (PATWARI NEAL K [US] ET AL) 5 September 2002 (2002-09-05) abstract figure 1 paragraphs [0024] - [0027]	1,17,19, 21,22
A	EP 1 731 919 A (DEUTSCHE TELEKOM AG [DE]) 13 December 2006 (2006-12-13) abstract figure 3 paragraphs [0020] - [0029]	1,17,19, 21,22
A	US 2006/290499 A1 (CHANG YUM-CHENG [TW]) 28 December 2006 (2006-12-28) abstract figures 1-4 paragraphs [0006] - [0010] paragraphs [0015] - [0021]	1,17,19, 21,22

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INTERNATIONAL SEARCH REPORT

Box No. II   Observations where certain claims were found unsearchable (Continuation of item 2 of first sheet)

This International search report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☒ Claims Nos.:
because they relate to parts of the International application that do not comply with the prescribed requirements to such an extent that no meaningful international search can be carried out, specifically:

   see FURTHER INFORMATION sheet PCT/ISA/210

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box No. III   Observations where unity of invention is lacking (Continuation of item 3 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

1. ☐ As all required additional search fees were timely paid by the applicant, this international search report covers allsearchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fees, this Authority did not invite payment of additional fees.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this international search reportcovers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this international search report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest   ☐ The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.

☐ The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.

☐ No protest accompanied the payment of additional search fees.

Form PCT/ISA/210 (continuation of first sheet (2)) (April 2005)

FURTHER INFORMATION CONTINUED FROM   PCT/ISA/ 210

Continuation of Box II.2

Claims Nos.:   —

The present claims 1, 17, 19, and 21-23 (together with claims 25, 27 and 29, which are correspondent with claim 23) relate to an extremely large number of possible methods or apparatusses. Support and disclosure in the sense of Article 6 and 5 PCT is to be found however for only a very small proportion of the method or apparatus claimed, see pages 4, 5 and 8. The non-compliance with the substantive provisions is to such an extent, that the search was performed taking into consideration the non-compliance in determining the extent of the search of claims 1, 17, 19, 21-23, 25, 27 and 29 (PCT Guidelines 9.19 and 9.21).

The applicant's attention is drawn to the fact that claims relating to inventions in respect of which no international search report has been established need not be the subject of an international preliminary examination (Rule 66.1(e) PCT). The applicant is advised that the EPO policy when acting as an International Preliminary Examining Authority is normally not to carry out a preliminary examination on matter which has not been searched. This is the case irrespective of whether or not the claims are amended following receipt of the search report or during any Chapter II procedure. If the application proceeds into the regional phase before the EPO, the applicant is reminded that a search may be carried out during examination before the EPO (see EPO Guideline C-VI, 8.2), should the problems which led to the Article 17(2)PCT declaration be overcome.

	International application No
	PCT/EP2007/009360

Patent document cited in search report		Publication date	Patent family member(s)		Publication date
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