

SYSTEM AND METHOD FOR DETERMINING THE DIRECTION OF A RADIO EMITTER

FIELD OF THE DISCLOSED TECHNIQUE

The disclosed technique relates to interferometers, in general, and to methods and systems for determining the direction of a radio emitter with resolved ambiguity in particular.

BACKGROUND OF THE DISCLOSED TECHNIQUE

Systems for determining the Direction Of Arrival (DOA) of electromagnetic radiation, emitted by a radio emitter are known in the art. A radio emitter is referred to herein as a device, which generates (i.e., a source) or reflects electromagnetic radiation at a frequency range extending substantially within the radio frequency band (e.g., between 30 kilo Hertz and 300 and Giga Hertz). Electromagnetic radiation emitted by a radio emitter is also referred to herein as a radio signal. One application of determining the DOA of a radio signal is, for example, determining the location a RADAR system. Another exemplary application is determining the location of a wireless transmitting node in a network (e.g., a cellular telephone or a node in an ad hoc network).

A known in the art technique used to determine the DOA of a radio signal is to determine the phase difference of a radio signal received by at least two antennas. In the two-dimensional (2D) case, a radio DOA determining system employs at least two antennas and measures the difference in the phase of the radio signal received by one antenna, relative to the radio signal received by the other antenna.

Reference is now made to Figure 1, which is a schematic illustration of a radio DOA determining system, generally referenced 10, which is known in the art. Radio DOA determining system 10 includes two

antennas, antenna 12 and antenna 14. The line extending between antenna 12 and antenna 14 defines a baseline for the radio interferometer, indicated by the line 16. A radio signal, indicated by lines 18₁ and 18₂ is received by antenna 12 and antenna 14 each producing a respective received signal (i.e., an electrical signal). The radio signal is received from a DOA θ , relative to a reference direction indicated by the dashed arrow 20. The DOA θ of the radio signal may cause a difference in phase between the received signal of antenna 12 and the received signal of antenna 14. The difference in phase between the received signal of antenna 12 and the received signal of antenna 14, relates to the DOA of the radio signal (i.e., the direction at which the radio emitter is located) as follows:

$$\Delta\phi = \left(2\pi d / \lambda\right) \sin \theta \quad (1)$$

where $\Delta\phi$ represents the difference in phase between the radio signal received by antenna 12 and antenna 14, d represents the relative distance between antenna 12 and antenna 14, λ represents the wavelength of the radio signal and θ represents the DOA of the radio signal. Equation (1) has a single solution as long as the relative distance d , between antenna 12 and antenna 14, is smaller or equal to half the wavelength of the radio signal (i.e., $d \leq \lambda/2$). Positioning the antennas at a relative distance larger than half the wavelength, may cause ambiguity in the determined DOA. This ambiguity in the determined DOA occurs since, when placing the antennas at a relative distance greater than half the wavelength, the number of repetitions of the wavelength associated with the radio signal, within the relative distance between the antennas, is greater than one. However, the repetitive nature of the radio signal limits the measured phase difference $\Delta\phi$ to be between 0 and 2π radians (i.e., to portions of a wavelength). Thus, when distance between the antennas is greater than half the wavelength, more than one wavelength repetitions

may be associated with the same measured phase difference (i.e., the measured phase difference may include integer multiples of 2π radians). This is also referred to as the wrapping or folding of the phase difference measurement $\Delta\phi$. Consequently, more than one DOA θ of the radio signal may be associated with the same measured phase difference $\Delta\phi$, which results in an ambiguity in the determined DOA. In such a case, the phase difference (i.e., in the two-dimensional case) is given by:

$$\Delta\phi = \left(2\pi d / \lambda\right) \sin \theta + 2\pi n_d \quad (2)$$

where n_d represents the number of times the wavelength λ repeats in the distance d between the antennas.

It is noted that the error in direction for a given phase difference measurement is given by:

$$\sigma_\theta = \frac{\lambda}{2\pi d \cos \theta} \sigma_{\Delta\phi} \quad (3)$$

where σ_θ represents the error in the direction, $\sigma_{\Delta\phi}$ represents the phase measurement error and where λ and d are as above in equation (1) and (2). According to equation (3), the error in the direction decreases as the distance between the antennas increases relative to the wavelength. Thus, it is desired to increase the distance between the antennas. However, as mentioned above, increasing this distance beyond half the wavelength introduces ambiguity to the determined direction.

U.S. Patent 4,639,733 to King et al, entitled "Direction Finding", directs to an interferometer system using an array of five antennas arranged at the apices of a regular pentagon. Two switches sequentially select a pair of antennas from the five antennas and provide the signal received by each of the two antennas to a respective receiver. A phase difference determinator determines the difference in phase between the two received signals and provides this difference in phase to a calculation device. The calculation device determines all possible bearings from the measured phase difference for each pair of antennas. A histogram is then

formed of the number of possible bearings in each range of possible bearings. In this histogram, a large number of possible bearings will occur in one of the possible bearings. Accordingly, the selected bearing shall be the range containing the number of possible bearings greater than a predetermined threshold.

U.S. Patent 5,021,792 to Hwang, entitled "System for Determining Direction or Attitude Using GPS Satellite Signals" directs to system, which uses the carrier phase of signals provided by GPS satellites for determining spatial orientation. The system includes an antenna array including three collinear antennas. Initially the antennas are equally distant apart and connected to three separate receivers. The carrier phase measurements are taken by each of the antenna/receiver combinations with respect to signals from four different satellites. The positions of two of the antennas are then exchanged, while continuously tracking the carrier phase. Phase measurements are again taken by each of the antenna/receiver combinations with respect to signals from the same four satellites. The antennas are then rearranged from the collinear arrangement to a non-collinear arrangement while continuously tracking the carrier phase. Phase measurements are yet again taken by each of the antenna/receiver combinations with respect to signals from the same four satellites at the non-collinear arrangement. The phase information gathered is then processed to resolve the phase ambiguities between the signals and the components of vectors representing the orientation of the antenna array based on the phase information by solving a set of equations.

U.S. Patent 2,860,336 to C. W. Earp et al, entitled "Radio Direction Finding System" directs to short wave direction-finding system, which includes a circular antenna array and a reference antenna. The individual antennas in the array are commutatively coupled one at a time at a given frequency to an array-receiving channel. The reference

antenna is also coupled to a respective reference-receiving channel. Another receiving channel, connected to the array-receiving channel and the reference-receiving channel produces a signal, which includes information relating to the phase difference between the signal received by the currently connected antenna in the antenna array and the reference antenna. The system directed to by Earp et al employs a circular antenna array instead of an antenna movable along a closed path since, according to Earp et al, in many cases it is not feasible to rotate an antenna at a reasonable gyration speed.

SUMMARY OF THE PRESENT DISCLOSED TECHNIQUE

It is an object of the disclosed technique to provide a novel method and system for determining the direction of a radio emitter with resolved ambiguity. In accordance with the disclosed technique, there is thus provided a system for determining the direction of arrival of a radio signal emitted by a radio emitter, relative to a reference direction. The system comprises at least two antennas, an antenna position determinator, a multi-channel radio receiver and a direction of arrival determinator. At least one of the at least two antennas is a moving antenna which moves through a plurality of measurement positions in a reference coordinate system and exhibits relative motion with respect to the other antenna. The distance between each selected pair of the at least two antennas is greater than half the wavelength of the radio signal. Each selected pair of the at least two antennas includes at least one of the at least one moving antenna. Each one of the at least two antennas receives the radio signal and produces a respective received signal. The antenna position determinator is coupled with each of the at least one of moving antenna. Each antenna is coupled with a respective channel in the multi-channel receiver. The direction of arrival determinator is coupled the multi-channel receiver and with each the at least one antenna position determinator.

The antenna position determinator determines the measurement positions of the at least one moving antenna in the reference coordinate system. The multi-channel radio receiver at least includes a respective phase difference detector for each selected pair of antennas. For each measurement position of a respective at least one moving antenna, each respective phase difference detector measures a phase difference between received signals produced by the antennas respective of the selected pair of antennas. The direction of arrival determinator associates each phase difference measurement respective of the selected pair

antennas with a respective measurement position of the respective at least one moving antenna at which the phase difference measurement was performed. For each selected pair of antennas and for each measurement position of the respective at least one moving antenna and respective phase difference measurement the direction of arrival determinator determines a respective set of possible directions of arrival from which the radio signal was received. The direction of arrival determinator selects the most probable direction of arrival as the direction of arrival of the radio signal from the respective sets of possible directions of arrival.

In accordance with another aspect of the disclosed technique, there is thus provided a method for determining the direction of arrival of a radio signal emitted by a radio emitter, relative to a reference direction. The method includes the procedures determining the frequency of the radio signal and measuring a phase difference between received signals produced by antennas respective of each selected pair of antennas. The selected pair of antennas includes at least one moving antenna. The phase difference is measured for each measurement position of the respective at least one moving antenna. The moving antenna moves through a plurality of measurement positions in a reference coordinate system and exhibiting relative motion with respect to the other antenna. The distance between each selected pair of the at least two antennas is greater than half the wavelength of the radio signal. Each antenna receives the radio signal and produces a respective received signal. The method further includes the procedures of determining a respective set of possible directions of arrival from which the radio signal was received for each selected pair of antennas and for each measurement position of the respective at least one moving antenna and determining the number of occurrences each potential direction of arrival was determined as a possible direction of arrival of the radio signal. The method also includes

the procedure of selecting the most probable DOA as the DOA of the radio signal.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosed technique will be understood and appreciated more fully from the following detailed description taken in conjunction with the drawings in which:

Figure 1 is a schematic illustration of a radio DOA determining system, which is known in the art.

Figure 2A is a schematic illustration of a system for determining the direction at which a radio emitter is located with resolved ambiguity in the DOA of the radio signal emitted by the radio emitter, constructed and operative in accordance with an embodiment of the disclosed technique.

Figures 2B-2F are schematic illustrations of an example for determining the DOA from which a radio signal was received in accordance with the embodiment of the disclosed technique described with reference to Figure 2A.

Figure 3 is a schematic illustration of a system for determining the direction in three-dimensions, at which a radio emitter is located with resolved ambiguity in the DOA of the radio signal emitted by the radio emitter, constructed and operative in accordance with another embodiment of the disclosed technique.

Figure 4 is a schematic illustration of a method, for determining the DOA of a radio emitter, operative in accordance with a further embodiment of the disclosed technique.

Figure 5A is a schematic illustration of a graph, representing the different possible DOAs of the radio signal, for each position of the moving antenna and for each one of three frequencies, f_1 , f_2 and f_3 in a frequency alteration sequence, in accordance with another embodiment of the disclosed technique.

Figure 5B is a schematic illustration of a graph, representing the histogram produced by the different position of the moving antenna and

for each one of the three frequencies, f_1 , f_2 and f_3 in the frequency alteration sequence.

DETAILED DESCRIPTION OF THE EMBODIMENTS

The disclosed technique overcomes the disadvantages of the prior art by providing a system and method for determining the Direction Of Arrival (DOA) of a radio signal with resolved ambiguity in the determined DOA. According to the disclosed technique, at least two antennas are employed where at least one of the antennas move relative through a plurality of measurement positions in a reference coordinate system. According to one embodiment of the disclosed technique, one antenna moves through a plurality of measurement positions (i.e., a moving antenna) and the other antenna is located at a fixed position (i.e., a stationary antenna). The distance between the antennas is larger than half the wavelength of the radio signal. Each measurement position of the moving antenna defines a respective different baseline with the stationary antenna. The difference in phase between the received signal produced by the moving antenna and the received signal produced by stationary antenna (i.e., for each selected different baseline), is measured at each position of the moving antenna. Accordingly, each phase measurement is associated with a respective measurement position of the moving antenna, and thus, with a respective baseline and relative distance between the antennas. For each measured phase difference, and thus for each measurement position of the moving antenna, a plurality of corresponding possible DOAs of the radio signal are determined (i.e., due to the above mentioned ambiguity in the DOA). In other words, a respective set of possible DOAs is determined for each measurement position of the moving antenna and respective measured phase difference. From the determined sets of possible DAOs, the most probable DOA is determined as the DOA of the radio signal. The most probable DOA is determined according to the number of occurrences of each determined possible DOA is a member of one of the sets of possible directions. For example, from the sets of possible DOA's (i.e., a set for

each measurement position of the moving antenna), a histogram of the possible DOAs is produced. This histogram represents the number of times each potential DOA in the histogram, has been determined as a possible DOA (i.e., each time a potential DOA was a member of one of the sets of possible DOAs). In other words, the histogram represents the number of times each possible DOA is a member in one of the sets of possible DOA's. The term 'potential DOAs' relates herein to all the directions within a selected range of directions at selected resolution (e.g., the range of directions between 0 and 180 degrees, relative to the reference direction, with a selected resolution of 0.1 of a degree). Each time a potential DOA is a member of a set of possible DOAs, is also referred to herein as a "hit". The potential DOA with the maximum number of occurrences is determined as the DOA θ of the radio signal and thus, the direction at which the radio emitter is located. Alternatively, the DOA θ with a number of occurrences, which exceeds a predetermined threshold, is determined as the DOA of the radio signal.

In general, the phase difference of the radio signal received by each of the antennas may also be represented as follows:

$$\Delta\phi = \left(\frac{2\pi}{\lambda} \right) (\vec{r} \bullet \vec{e}) + 2\pi n \quad (4)$$

where $\vec{r}$ represents the relative position vector between the antennas, $\vec{e}$ represents the unit vector of the direction of the radio emitter and ' $\bullet$ ' represents the vector dot product. Accordingly, in general, the disclosed technique attempts to determine the DOA θ , which minimizes the difference between the measured phase difference and expected phase difference of the received radio signal for each of the possible DOAs as follows:

$$\hat{\theta} = \arg \min_{\theta} \sum_i \Delta\hat{\phi}_i - \left(\frac{2\pi d}{\lambda} \right) (\vec{r}_i \bullet \vec{e}(\theta)) \quad (5)$$

According to an embodiment of the disclosed technique, the moving antenna is mechanically coupled with a rotating platform and the

stationary antenna is located at a fixed position, a distance D from the axis of rotation, of the rotating platform. The position of the stationary antenna, relative to the axis of rotation of the rotating platform is known. As the platform rotate, the position of the moving antenna changes. Thus, the moving antenna moves through a plurality of measurement positions in a reference coordinate system. The position of the moving antenna is determined according to the position of the axis of rotation of the rotating platform, the distance of the moving antenna from the axis of rotation of the platform and the angular position of a line extending between the axis of rotation of the platform with the moving antenna, relative to a reference direction. As the moving antenna rotates, the different positions at which the moving antenna is located, define respective baselines with the stationary antenna.

Reference is now made to Figures 2A-2F. Figure 2A is a schematic illustration of a system, generally referenced 100, for determining the direction at which a radio emitter is located with resolved ambiguity in the DOA of the radio signal emitted by the radio emitter, constructed and operative in accordance with an embodiment of the disclosed technique. Figures 2B-2F are schematic illustrations of an example for determining the DOA from which a radio signal was received in accordance with the embodiment of the disclosed technique described with reference to Figure 2A.

With reference to Figure 2A, system 100 includes two antennas, a moving antenna 102, a stationary antenna 104. System 100 further includes a rotating platform 106, an antenna position determinator 108, a dual channel receiver 110 and a DOA determinator 114. Dual channel receiver 110 further includes a phase difference detector 112. Stationary antenna 104 is located at a known position relative to rotation axis 120 of rotating platform 106. Thus, the distance between rotation axis 120 of rotating platform 106 and stationary antenna 104 is denoted D . The

instantaneous distance between the current position of moving antenna 102 and stationary antenna 104 is denoted d .

Moving antenna 102 is mechanically coupled with rotating platform 106. Antenna position determinator 108 is coupled with DOA determinator 114 and with rotating platform 106 via a motor (not shown) such as an electric motor or an internal combustion engine, which rotates the platform. Antenna position determinator 108 may also be coupled with an angular position determinator (not shown) which provides the angular position α , of a line extending between the rotation axis 120 of rotation platform 106 with the moving antenna 102 relative to a reference direction indicated by dashed arrow 116. Dual channel receiver 110 is coupled with each one of moving antenna 102 and stationary antenna 104 and with DOA determinator 114.

It is noted that the angular position determinator may be incorporated with the motor or with antenna position determinator 108. Furthermore, in Figure 2, moving antenna 102 is depicted as coupled on the rim of rotating platform 106. However, it is noted that moving antenna 102 can be located anywhere on rotating platform 106 as long as the distance R of antenna 102, from rotation axis 120 of rotating platform 106, is known. Furthermore, in Figures 2A-2D, rotating platform 106 is depicted as exhibiting the shape of a circular disc. However, rotating platform 106 may exhibit any other shape (i.e., geometrical or arbitrary) so long as the distance between the axis of rotation of the rotating platform and the moving antenna is known.

System 100 determines the direction at which a radio emitter (not shown) is located in two-dimensions. In two-dimensions, the direction of the radio emitter may be represented by an angle relative to a reference direction (e.g., bearing when the reference direction is the north or azimuth). Alternatively, the direction of the radio emitter may be represented by a unit vector, exhibiting a direction corresponding to the

direction at which the radio emitter is located. In Figures 2A-2D, the reference direction is represented by dashed arrow 116, which is perpendicular to line 122, thus defining a plane. In Figures 2A-2D, the line 122 extending between stationary antenna 104 and rotation axis 120 of rotating platform 106 defines a two-dimensional coordinate system 124 with the position of stationary antenna 104 being the origin of coordinate system 124. Accordingly, the positions of stationary antenna 104 and rotation axis 120 of rotating platform 106, in reference coordinate system 124 are known. Reference coordinate system 124 may be registered with, or one of a geographical coordinate system such geographical latitude longitude, WGS84, GRS80, OSGB36, ED50 and the like. The term "registered" refers to herein to every position in the reference coordinate system having a corresponding known position in the geographical coordinate system).

Rotating platform 106 rotates, for example, in the direction indicated by arrow 118. Antenna position determinator 108 determines the measurement position of moving antenna 102 in reference coordinate system 124. To that end, for example, the angular position determinator detects the angular position α of moving antenna 102 (i.e., of the line extending between rotation axis 120 of rotating platform 106 with moving antenna 102) relative to the reference direction 116. The angular position determinator provides this detected angular position α to antenna position determinator 108. The angular position determinator may determine the angular position α of moving antenna 102 by detecting (i.e., to a desired degree of accuracy) the Time Of Arrival (TOA) of the radio signal modulo a complete rotation interval of rotating platform 106. Thereafter angular position determinator determines the ratio between this modulo TOA and the complete rotation interval and multiplying by 360. For example, the angular position determinator determines the complete rotation interval of rotating platform 106 by averaging a plurality of measurements of the

respective intervals of a plurality of rotations. Angular position determinator determines the time interval between the time at which antenna 102 passed through reference direction 116 and the Time Of Arrival (TOA) of the radio signal at moving antenna 102. Angular position determinator divides this interval by the complete rotation interval and multiplies the result of this division by 360 to determine the angular position α of moving antenna 102.

Antenna position determinator 108 determines the measurement position of moving antenna 102, in reference coordinate system 124, according to the distance R of moving antenna 102 from rotation axis 120 of rotating platform 106, the position of rotation axis 120 of rotating platform 106 in coordinate system 124 and the angular position α of moving antenna 102. Alternatively, antenna position determinator 108 directs moving antenna 106 to move through a plurality measurement positions in reference coordinate system 124. To that end, for example, antenna position determinator 108 determines the angle α corresponding to each measurement position and directs the motor to rotate moving platform to that angle. According to another alternative, antenna position determinator 108 may alternatively be embodied as a GPS receiver attached to moving antenna 102, determining the measurement position thereof and providing the position of moving antenna 102 to DOA determinator 114. Antenna position determinator 108 provides the determined measurement position of moving antenna 102 to DOA determinator 114.

Each one of moving antenna 102 and stationary antenna 104 receives a radio signal originating from the same radio emitter and produced a respective received signal (i.e., an electrical signal). Each one of moving antenna 102 and stationary antenna 104 provides the respective received signal produced thereby to dual channel receiver 110. Dual channel receiver 110 receives the received signals from moving

antenna 102 and stationary antenna 104 and performs substantially identical reception operations on each of the received signals. These reception operations include, for example, down conversion, filtering, sampling, demodulation, equalization and the like. For each measurement position of moving antenna 102, phase difference detector 112 determines the respective difference in phase $\Delta\phi$, also referred to herein as phase difference measurement, between the received signal produced by moving antenna 102 and the received signal produced by stationary antenna 104. Dual channel receiver 110 provides this phase difference measurement $\Delta\phi$ to DOA determinator 114. Furthermore, Dual channel receiver 110 determines the frequency of the received signal (e.g., by employing Fourier Transform techniques) and provides this frequency to DOA determinator 114. Alternatively, the user may know the frequency of the emitter (e.g., via intelligence or published information) and provides this frequency to DOA determinator 114. The frequency of the radio signal may be, for example, the carrier frequency in case the radio signal is a modulated signal or the minimum frequency of the bandwidth of the radio signal. It is noted that dual channel receiver 110 may be replaced with two separate receivers, each coupled with a respective one of moving antenna 102 and stationary antenna 104, and a separate phase difference detector, coupled with the two separate receivers, as long as these receivers are coherent (i.e., synchronized samplers clocks) and synchronized with respect to their output.

DOA determinator 114 associates each one of the phase difference measurements received from receiver 110, with a respective measurement position of moving antenna 102 (i.e., receive from antenna position determinator 108) at which that phase difference measurement $\Delta\phi$ was measured and thus, with a respective baseline. DOA determinator 114 further determines the angle β between line 122 and the line extending between moving antenna 102 and stationary antenna 104.

For each phase difference measurement $\Delta\phi$ and the respective measurement position of moving antenna 102, DOA determinator 114 determines a set of possible directions from which the radio signal was received, according to the following:

$$\Theta = \left\{ \arcsin\left(\frac{\lambda(\Delta\phi - 2\pi i)}{2\pi d}\right) \mid i \in \mathbb{Z} \text{ and } 0 \leq i \leq \lceil n_d \rceil - 1 \right\} \quad (6)$$

where Θ represents a set of all possible DOAs from which the radio signal was received and n_d represents the number of times the wavelength λ repeats in the instantaneous distance d between moving antenna 102 and stationary antenna 104 (i.e., since d may differ for each measurement position of moving antenna 102 n_d may also be different).

Furthermore, i is an integer (i.e., a member of the set of all integers $\mathbb{Z}$) between zero and $\lceil n_d \rceil$ where $\lceil \cdot \rceil$ represents the round-up operator. It is noted that DOA determinator 114 determines the wavelength λ and, thus n_d , according to the determined frequency of the radio signal. DOA determinator 114 further determines the instantaneous distance d according to the relative position between moving antenna 102 and stationary antenna 104, respectively.

When determining the sets of possible DOAs, DOA determinator 114 also accounts for the angle β between line 122 and the line extending between the two antennas (i.e., DOA determinator 114 subtracts the angle β from the determined DOAs). DOA determinator 114 determines the most probable DOA as the DOA of the radio signal, from the determined sets of possible DOAs. For example, DOA determinator 114 produces a histogram representing the number of times each one of the potential DOAs in the histogram has been determined as a possible DOA in one of the determined sets. DOA determinator 114 determines the DOA exhibiting the largest number of occurrences (i.e., hits) as the direction from which the radio signal was received and thus, the direction

at which the radio emitter is located. Alternatively, DOA determinator 114 determines the most probable DOA, the thus the DOA of the radio signal, when the number of occurrences of one of the possible directions exceeds a predetermined threshold. According to another alternative, DOA determinator 114 estimates from the histogram a probability density function mapping each potential DOA with to a probability that that potential DOA is the DOA of the radio signal. DAO determinator 114 determines the potential DOA at which this probability density function exhibits a maximum value as the DOA of the radio signal.

With reference to Figure 2B-2F, following is an example for determining the direction from which a radio signal was received according to the embodiment of the disclosed technique described above in conjunction with Figure 2A. In the example set forth in Figures 2B-2F, the frequency of the radio signal is 100 Megahertz (MHz), the distance R of moving antenna 102 from rotation axis 120 of rotating platform 106 is 0.5 meters (abbreviated by the letter m in Figures 2B-2F - $R = 0.5m$). The distance D of the stationary antenna 104 from rotation axis 120 of rotating platform 106 is 10 meters (i.e., $D = 10m$). Similar to Figure 2A, the line 122 between stationary antenna 104 and rotation axis 120 of rotating platform 106 defines two-dimensional reference coordinate system 124 with the position of stationary antenna 104 being the origin of coordinate system 124. Furthermore, the reference direction is represented by dashed arrow 116, which is perpendicular to line 122.

With reference to Figure 2B, moving antenna 102 is located at a first measurement position, represented by coordinates $[x=10.5, y=0]$ in reference coordinate system 124. The angular position α , of a line extending between rotation axis 120 of rotating platform 106 with the moving antenna 102, relative to a reference direction 116 is 90 degrees (i.e., $\alpha = 90^\circ$). The instantaneous distance d is thus, 10.5 meters (i.e., $d = 10.5m$). The angle β between line 122 and the line extending between

the two antennas is zero degrees (i.e., $\beta = 0^\circ$). Employing equation (6) with $d = 10.5m$, $\lambda = 3m$ and corresponding phase difference measurement $\Delta\phi$ of 270 degrees (i.e., $\Delta\phi = 270^\circ$), the set Θ_1 of possible DOAs of the radio signal relative to reference direction 116 is:

$$\Theta_1 = [-4.09601, -20.9248, -40.0052, -68.2136, 12.27365, 30, 51.78668]$$

where the values in Θ_1 are given in degrees and the subscript indicates the index of the measurement position of moving antenna 102.

With reference to Figure 2C, moving antenna 102 rotated in the direction indicated by arrow 118 and to a second measurement position, represented by coordinates $[x=9.706, y=-0.4]$ in reference coordinate system 124. The angular position α , of a line extending between the axis of rotation of the platform with the moving antenna 102 relative to a reference direction 116 is 218.66 degrees (i.e., $\alpha = 218.66^\circ$). The instantaneous distance d is thus, 9.715 meters (i.e., $d = 9.715$). The angle β between line 122 and the line extending between the two antennas is minus 2.4 degrees (i.e., $\beta = -2.4^\circ$). Employing equation (6) with $d = 9.715$, $\lambda = 3m$ and corresponding phase difference measurement of 180.3 degrees (i.e., $\Delta\phi = 180.3^\circ$) and subtracting the angle $\beta = -2.4^\circ$ from the results, the set Θ_2 of possible DOAs of the radio signal relative to reference direction 116 is:

$$\Theta_2 = [-6.48109, -25.1928, -48.1290, 11.28447, 30, 52.95081]$$

where the values in Θ_2 are also given in degrees.

With reference to Figure 2D, moving antenna 102 rotated in the direction indicated by arrow 118 to a third measurement position, represented by coordinates $[x=9.706, y=0.4]$ in reference coordinate system 124. The angular position α , of a line extending between the axis of rotation of the platform with the moving antenna 102 relative to a reference direction 116 is 321.34 degrees (i.e., $\alpha = 312.34^\circ$). The instantaneous distance d is thus, yet again, 9.715 meters (i.e., $d = 9.715$).

The angle β between line 122 and the line extending between the two antennas is 2.4 degrees (i.e., $\beta = 2.4^\circ$). Employing equation (6) with $d = 9.715$, $\lambda = 3m$ and corresponding phase difference measurement of 264 degrees (i.e., $\Delta\phi = 264^\circ$) and subtracting the angle $\beta = 2.4^\circ$ from the results, the set Θ_3 of possible DOAs of the radio signal relative to reference direction 116 is:

$$\Theta_3 = [-7.08915, -25.39, -46.7804, 10.72345, 30, 55.22543]$$

where the values in Θ_3 are also given in degrees.

With reference to Figure 2E, graph 150 represents the different possible directions for each measurement position of moving antenna 102. The horizontal axis 152 represents the potential DOAs in degrees (i.e., all the direction between -90 to 90 degrees) and the vertical axis 152 represents the index the position of moving antenna 102. With reference to Figure 2F, graph 160 represents a histogram of the different possible DOAs of the radio signal relative to reference direction 116, for each measurement position of moving antenna 102. The horizontal axis 162 represents the histogram potential DOAs in degrees and the vertical axis 164 represents the number of occurrences (i.e., hits). As seen in graph 160, the DOA θ of 30 degrees (i.e., $\theta = 30^\circ$) is the most occurring DOA (i.e., exhibits the maximum number of occurrences - three). Therefore, with reference to Figures 2A-2D, DOA determinator 114 determines that the radio emitter is located at a direction of 30 degrees relative reference direction 116. Alternatively, DOA determinator 114 determines the DOA θ , as the DOA of the radio signal, when the number of occurrences of one of the possible DOAs exceeds a predetermined threshold. For example, when number of occurrences exceeds a predetermined threshold of two, DOA determinator 114 also determines that the radio emitter is located at a direction of 30 degrees relative reference direction 116.

In general, the number of measurement positions of the moving antenna, used when determining the DOA θ of the radio signal, should be

chosen (e.g., heuristically) such that the histogram shall not become cladded with different possible direction and thus un-discernable. For example, only the last 10 or the last 100 positions of moving antenna are used when determining the DOA of the radio signal. Furthermore, the accuracy of the determined DOA depends also on the accuracy of the distance between the antennas. Thus, in the above embodiment described in conjunction with Figures 2A-2B, the angular position determinator of the rotating platform 106 should be selected to provide the angular position of rotating platform 106 with a degree of accuracy, such that the position of moving antenna 102, and consequently the instantaneous distance, d , between moving antenna 102 and stationary antenna 104, is determined with the desired degree of accuracy.

In the embodiments described above in conjunction with Figures 2A-2F, the moving antenna is located on a rotating platform. According to another embodiment of the disclosed technique, the moving antenna may be located on a transversally moving platform (e.g. moving left to right or forwards and backwards or a combination thereof). For example, the moving platform is located on a rail and a linear position encoder determines the position of the platform on the rail relative to a reference position. The coordinates of the reference position and direction at which the rail is oriented, in the reference coordinate system, are known. Thus, the position of the moving antenna in the reference coordinate system can also be determined. Consequently, the instantaneous distance, d , between the moving antenna and stationary antenna 104 is determined.

The above description with reference to Figures 2A-2F relates to determining the DOA of a radio signal in a two-dimensional reference coordinate system (e.g., either azimuth or elevation). However, the disclosed technique may also be employed for determining the DOA of a radio signal in a three-dimensional reference coordinate system as well. By adding an additional antenna (i.e., either a stationary antenna or a

moving antenna), which creates two additional baselines with each of the other two antennas, the DOA of a radio signal may be determined in a three-dimensional coordinate system (e.g., both azimuth and elevation).

Reference is now made to Figure 3, which is a schematic illustration of a system, generally referenced 200, for determining the direction in three-dimensions, at which a radio emitter is located with resolved ambiguity in the DOA of the radio signal emitted by the radio emitter, constructed and operative in accordance with another embodiment of the disclosed technique. System 200 includes three antennas, a moving antenna 202, a first stationary antenna 204, and a second stationary antenna 206. System 200 further includes a rotating platform 208, an antenna position determinator 210, a triple channel receiver 212 and a DOA determinator 218. Triple channel receiver 212 further includes a first phase difference detector 214 and a second phase difference detector 216. First stationary antenna 204 and second stationary antenna are located at known positions relative to the rotation axis 222 of rotating platform 208. Thus, the distance between the rotation axis 224 of rotating platform 208 and first stationary antenna 204 is D_1 . The distance between the rotation axis 222 of rotating platform 208 and second stationary antenna 206 is D_2 . The instantaneous distance between the current position of moving antenna 202 and first stationary antenna 204 is d_1 and the instantaneous distance between the current position of moving antenna 202 and stationary antenna 206 is d_2 .

Moving antenna 202 is mechanically coupled with rotating platform 208. Antenna position determinator 210 is coupled with DOA determinator 218 and with rotating platform 208 via a motor (not shown) such as an electric motor, a hydraulic motor, an internal combustion engine and the like, which rotates the platform. Antenna position determinator 210 may also be coupled with an angular position determinator (not shown) which provides the angular position α , of a line

extending between the axis of rotation of the platform with the moving antenna 202 relative to a reference direction indicated by dashed arrow 224. Each one of moving antenna 202, first stationary antenna 204 and second stationary antenna is coupled with a respective channel of triple channel receiver 212. Triple channel receiver is further coupled with DOA determinator 218. In general, a multi-channel receiver is used, including N channels where each antenna is coupled with a respective channel. Furthermore, the multi-channel receiver includes M phase difference detectors, each phase difference detector detecting the phase difference between signals received by respective M selected pairs of antennas.

It is noted that the angular position determinator may be incorporated with the motor or with Antenna position determinator 210. Furthermore, in Figure 3, moving antenna 202 is depicted as coupled at the rim of rotating platform 208. However, it is noted that moving antenna 202 can be located anywhere on rotating platform 208 as long as the distance R of antenna 202, from axis of rotation 224 of rotating platform 208, is known. Furthermore, in Figure 3, rotating platform 208 is depicted as exhibiting the shape of a circular disc. However, rotating platform 208 may exhibit any other shape (i.e., geometrical or arbitrary) so long as the distance between the axis of rotation of the rotating platform and the moving antenna is known.

System 200 determines the direction at which a radio emitter (not shown) is located in three-dimensions. In three-dimensions, the direction of the radio emitter may be represented by two angles (e.g., azimuth and elevation), each relative to a respective reference direction, where the two reference directions are perpendicular one relative to the other. Alternatively, the direction may be represented by a unit vector, exhibiting a direction corresponding to the direction at which the radio emitter is located. In Figure 3, the line 224 extending between first stationary antenna 204 and the line 226 define a first plane. Line 224 and

line 230 define a second plane. These two planes, both define a three-dimensional reference coordinate system 230. Accordingly, the positions of first stationary antenna 204, second stationary antenna 206 and the rotation axis 222 of rotating platform 208 are known in reference coordinate system 230. It is noted that reference coordinate system 230 may be registered with, or one of a geographical coordinate system such as geographical latitude longitude, WGS84, GRS80, OSGB36, ED50 and the like. In general, the three antennas define a plane. This plane, along with the normal thereto, defines a three-dimensional space, which may be associated with a three-dimensional coordinate system.

Rotating platform 208 rotates, for example, in the direction indicated by arrow 220. Antenna position determinator 210 determines the measurement position of moving antenna 202 in reference coordinate system 230. To that end, the angular position determinator detects the angular position α of moving antenna 202 (i.e., of the line extending between the axis of rotation 222 of rotating platform 208 with moving antenna 202) relative to the reference direction 226. The angular position determinator provides this detected angular position α to antenna position determinator 210. Antenna position determinator 210 determines the measurement position of moving antenna 202, in reference coordinate system 228, according to the distance R of moving antenna 202 from the axis of rotation 222 of rotating platform 208, the position of rotation axis 222 of rotating platform 208 in coordinate system 228 and the angular position α of moving antenna 202. Antenna position determinator 210 provides the determined measurement position of moving antenna 202 to DOA determinator 218. Similar to as described above in conjunction with Figure 2A, antenna position determinator 210 may direct moving antenna 106 to move through a plurality of measurement positions in reference coordinate system 230. To that end, for example, antenna position determinator 210 determines the angle α corresponding to each

measurement position and directs the motor to rotate moving platform to that angle. As a further alternative, antenna position determinator 210 may be embodied as a GPS receiver attached to moving antenna 202 and determining the measurement position thereof and provides the position of moving antenna 202 to DOA determinator 218.

Each one of moving antenna 202, first stationary antenna 204 and second stationary antenna 206 receives a radio signal originating from the same radio emitter and produced a respective received signal. Each one of moving antenna 202, first stationary antenna 204 and second stationary antenna 206 provides the respective received signal produced thereby to triple channel receiver 212. Triple channel receiver performs substantially identical reception operations on each of the respective received signals. These reception operations include, for example, down conversion, filtering, sampling, demodulation, equalization and the like. Furthermore, triple channel receiver determines the frequency of the received signal (e.g., the carrier frequency in case the radio signal is a modulated signal) and provides this frequency to DOA determinator 220. Alternatively, as mentioned above, the user may know the frequency of the emitter and provide this frequency to DOA determinator 114. Similar to dual channel receiver 110 (Figure 2A), triple channel receiver 212 may be replaced with three separate receivers, or two dual channel receivers as long as these receivers are coherent (i.e., synchronized samplers clocks) and synchronized with respect to their output.

For each measurement position of moving antenna 202, first phase difference detector 214 determines a first difference in phase $\Delta\phi_1$, between the radio signal received by moving antenna 202 and by first stationary antenna 204. The first difference in phase $\Delta\phi_1$ is used to determine, for example, the azimuth angle from which the radio signal was received. Furthermore, for each measurement position of moving antenna 202, second phase difference detector 216 determines a second

difference in phase $\Delta\phi_2$, between the radio signal received by moving antenna 202 and by second stationary antenna 206. The second difference in phase $\Delta\phi_2$ is used to determine, for example, the elevation angle from which the radio signal was received. Triple channel receiver 212 provides the phase difference measurement $\Delta\phi_1$ and $\Delta\phi_2$ to DOA determinator 218. It is noted that measuring the phase difference between stationary antenna 204 and stationary antenna 206 is optional since the phase difference between these two antennas is constant for a given frequency and radio emitter location.

DOA determinator 218 associates each one of phase difference measurements, received from receiver 212 with a respective measurement position of moving antenna 202 (i.e., receive from antenna position determinator 210) at which that phase difference measurement $\Delta\phi_1$ and $\Delta\phi_2$ was acquired and thus, with a respective baseline. DOA determinator 218 further determines the angle β between line 224 and the line extending between moving antenna 202 and first stationary antenna 204, as well as the angle γ between line 230 and the line extending between moving antenna 202 and second stationary antenna 230.

For each phase difference measurement $\Delta\phi_1$ and the respective measurement position of moving antenna 202, DOA determinator 218 determines a first set of possible directions (e.g., azimuths) from which the radio signal was received, according to the following:

$$\Theta = \left\{ \arcsin\left(\frac{\lambda(\Delta\phi_1 - 2\pi i)}{2\pi d_1^i}\right) \mid i \in Z \text{ and } 0 \leq i \leq \lceil n_{d_1} \rceil - 1 \right\} \quad (7)$$

where Θ represents the first set of all possible DOAs from which the radio signal was received and n_{d_1} represents the number of times the wavelength λ repeats in the instantaneous distance d_1^i between moving antenna 202 and stationary antenna 204 (i.e., since d_1^i may differ for each position of moving antenna 202 n_{d_1} may also be different).

Furthermore, i is an integer (i.e., a member of the set of all integers $\mathbb{Z}$) between zero and n_{d_1} where $\lceil \cdot \rceil$ represents the round-up operator.

For each phase difference measurement $\Delta\phi_2$ and the respective measurement position of moving antenna 202, DOA determinator 218 determines a second set of possible directions (e.g., elevations) from which the radio signal was received, according to the following:

$$\Xi = \left\{ \arcsin\left(\frac{\lambda(\Delta\phi_2 - 2\pi i)}{2\pi d_2^i}\right) \mid i \in \mathbb{Z} \text{ and } 0 \leq i \leq \lceil n_{d_2} \rceil - 1 \right\} \quad (8)$$

where Ξ represents the second set of all possible DOAs from which the radio signal was received and n_{d_2} represents the number of times the wavelength λ repeats in the instantaneous distance d_2^i between moving antenna 202 and stationary antenna 206 (i.e., since d_2^i may differ for each position of moving antenna 202 n_{d_2} may also be different). Furthermore, i is an integer (i.e., a member of the set of all integers $\mathbb{Z}$) between zero and n_{d_2} . It is noted that DOA determinator 220 determines the wavelength λ and, thus n_{d_1} and n_{d_2} , according to the determined frequency of the radio signal. DOA determinator 220 further determines the instantaneous distances d_1^i and d_2^i according to the relative position between moving antenna 202 and stationary antenna 206, respectively.

For each measurement position of moving antenna 202, DOA determinator 220 determines the sets, Θ and Ξ , of possible DOAs of the radio signal. For example, the set Θ represents the set of possible azimuth angles and the set Ξ represents the set of possible elevation angles. When determining these DOAs, DOA determinator 220 accounts for the angles β and γ (i.e., DOA determinator 114 subtracts these angles from the determined DOAs). DOA determinator 220 determines the most probable DOAs as the DOAs of the radio signal and thus, the direction at which the radio emitter is located, from the determined sets of possible

DOAs. For example, DOA determinator 218 produces two histograms each representing the number of times each one of the potential DOAs in the histogram has been determined as a possible DOA in the respective set.

Alternatively, DOA determinator 218 produces a three-dimensional histogram, one axis represents potential azimuth angles, the second axis represents potential elevation angles and the third axis represents the number of occurrences. The combination of azimuth and elevation angles exhibiting the largest number of occurrences are selected as the azimuth and elevation angle of the emitter

The most probable DOA may be the most occurring DOA. Alternatively, the DOA determinator 218 determines the possible direction with a number of occurrences, which exceeds a predetermined threshold as the most probable DOA and thus, as the DOA of the radio signal.

The embodiment described above in conjunction with Figures 2A-2F and Figure 3 includes using pairs of antennas where at least one of the antennas is a moving antenna. However, the disclosed technique is not limited thereto. Additional antennas (i.e., either stationary or moving) may be used, which define additional pairs of antennas. Each additional pair of antennas define a respective baseline (i.e., when both antennas are stationary) or respective plurality of baselines (i.e., when at least one of the antennas of the additional pair is a moving antenna moving through a plurality of respective measurement positions in a reference coordinate system).

Furthermore, not all of the possible pairs of antennas must be used to determine the DOA of the radio signal. Selected pairs of antennas are may be employed, where the number of selected pairs may be smaller than the number of possible pairs of antennas. Accordingly, a phase difference detector, respective of each selected pair of antennas, measures the respective phase difference between the received signals

produced by the antennas respective of the selected pair of antennas (i.e., the baseline defined by the antennas is associated with a respective phase difference measurement). When the selected pair of antennas includes a moving antenna, the respective phase difference detector measures the phase difference between the received signals produced by the antennas respective of the selected pair, for each measurement position of the respective moving antenna (i.e., each baseline of the plurality of baselines is associated with a respective phase difference measurement). Each baseline and respective phase difference measurement, results in a respective set of possible DOAs, which may be used as described above when determining the DOA of the radio signal. Furthermore, when more than one moving antenna is employed, the antenna position determinator may be distributed (i.e., determining the position of each antenna separately) or centralized (i.e., determining the positions of all the moving antennas)

Reference is now made to Figure 4, which is a schematic illustration of a method, for determining the DOA of a radio emitter, operative in accordance with a further embodiment of the disclosed technique. In procedure 250, a phase difference $\Delta\phi$ is measured between received signals produced by the antennas respective of each selected pair of antennas including at least one moving antenna, for each measurement position of a respective at least one moving antenna. The at least one moving antenna moves through a plurality of measurement positions in a reference coordinate system and exhibits relative motion with respect to the other antenna. With reference to Figure 2A, dual channel receiver 110 receives a signal from each one of moving antenna 102 and stationary antenna 104 and phase difference detector 114 determines the phase difference $\Delta\phi$ between the received signals.

In procedure 252, the frequency of the received radio signal is determined. The frequency of the received signal may be determined, for

example, by employing Fourier Transform techniques. Alternatively, a user may know the frequency of the radio emitter (e.g., via intelligence or published information). With reference to Figure 2A, dual channel receiver 110 determines the frequency of the received radio signal.

In procedure 254, a respective set of possible directions of arrival from which the radio signal was received is determined for each of the selected pair of antennas, and for each measurement position of the respective at least one moving antenna. With reference to Figure 2A, DOA determinator 114 determines a set of possible DOAs of the radio signal.

In procedure 256, the number of occurrences where each potential DOA has been determined as a possible DOA of the radio signal is determined. The number of occurrences may be determined by employing a histogram. The histogram represents the number of times each potential DOA has been determined as a possible DOA. With reference to Figure 2A, DOA determinator 114 produces a histogram representing the number of times each one of the possible DOAs has been determined as a possible DOA.

In procedure 258, the most probable DOA θ is selected as the DOA of the radio signal. The most probable DOA may be the most occurring DOA. Alternatively, when one of the possible DOAs exceeds a predetermined threshold, that DOA is determined as the most probable DOA and thus, as the DOA of the radio signal. With reference to Figure 2A, DOA determinator 114 selects the DOA θ exhibiting the maximum number of occurrences as the most probable DOA and thus, as the DOA of the radio signal. Alternatively, DOA θ determinator 114 determines the most probable DOA, and thus the DOA of the radio signal, when the number of occurrences of one of the possible directions exceeds a predetermined threshold.

In general, as mentioned above, according to the disclosed technique at least two antennas move one relative to the other through a plurality of relative positions. When several or all of the antennas move, the position of each antenna may be determined, for example, with a respective GPS receiver attached thereto. Alternatively, the relative position between the antennas may be determined with optical or magnetic tracking systems attached to the moving antennas.

The disclosed technique may also be employed when the radio signal exhibits frequency alteration. In accordance with another embodiment of the disclosed technique, a histogram, similar to as described above with reference to Figures 2A-2F is produced for each frequency. The DOA determinator determines the most probable DOA θ , for all the frequencies in a frequency alteration sequence. When employing a histogram, the DOA determinator determines the DOA θ with the maximum number of occurrences for all the frequencies in the frequency alteration sequence (i.e., summing over all the baselines and all the frequencies) as the DOA θ of the radio signal.

Reference is now made to Figures 5A and 5B. Figure 5A is a schematic illustration of a graph, generally referenced 280, representing the different possible DOAs of the radio signal, for each position of the moving antenna and for each one of three frequencies, f_1 , f_2 and f_3 in a frequency alteration sequence, in accordance with another embodiment of the disclosed technique. In Figure 5A, the horizontal axis 282 represents the potential DOAs in degrees (i.e., all the direction between -90 to 90 degrees), the vertical axis 284 represents the index the relative positions between the antennas and the axis 286 represents the different frequencies of the frequency altering signal. Figure 5B is a schematic illustration of a graph, generally referenced 290, representing the histogram produced by the different position of the moving antenna and for each one of the three frequencies, f_1 , f_2 and f_3 in the frequency

alteration sequence. In Figure 5B, the horizontal axis 292 represents the potential DOAs in degrees the vertical axis 294 represents the vertical axis represents the number of occurrences. As seen in Figure 5B, the direction of 30 degrees (i.e., $\theta = 30^\circ$) exhibits the largest number of occurrences. Alternatively, when one of the possible DOAs exceeds a predetermined threshold, then that DOA is determined as the DOA θ of the radio signal. For example, when this threshold is determined to be six, then, yet again, the direction of 30 degrees (i.e., $\theta = 30^\circ$) is determined as the DOA of the radio signal.

According to another embodiment of the disclosed technique, a plurality of antenna pairs are used to receive radio signals over a wide spectral band where each antenna pair receives radio signals over a respective portion of the wide spectral band. An 'antenna pair' refers to herein to a moving antenna and a stationary antenna. For example, for a spectral band Δf and two pairs of antennas pairs, the first antenna pair receives the lower portion of Δf and the second antenna pair receiver the upper portion of Δf .

As mentioned above, a system for determining the DOA of a radio signal may be employed when determining the position of a radio emitter in a reference coordinate system. According to a further embodiment of the disclosed technique, at least two systems, each similar to the system described above in conjunction with Figure 2A or in conjunction with Figure 3, are employed for determining the position of a radio emitter in a two-dimensional or three-dimension coordinate systems respectively. The positions of these two systems, in the two-dimensional coordinate system, are known. Each system determines a respective DOA of the radio signal and thus. Each DOA defines a line in the two-dimensional coordinate system passing between the respective station and the radio emitter. The intersection of these two lines determines the position of the radio emitter.

It will be appreciated by persons skilled in the art that the disclosed technique is not limited to what has been particularly shown and described hereinabove. Rather the scope of the disclosed technique is defined only by the claims, which follow.

CLAIMS

1. A system for determining the direction of arrival of a radio signal emitted by a radio emitter, relative to a reference direction comprising:

at least two antennas, at least one of said at least two antennas being a moving antenna moving through a plurality of measurement positions in a reference coordinate system and exhibiting relative motion with respect to the other antenna, the distance between each selected pair of said at least two antennas being greater than half the wavelength of said radio signal, each said selected pair of said at least two antennas including at least one of said at least one moving antenna, each one of said at least two antennas receiving said radio signal and producing a respective received signal;

an antenna position determinator, coupled with each of said at least one of moving antenna, said antenna position determinator determining said measurement positions of said at least one moving antenna in said reference coordinate system;

a multi-channel radio receiver, each antenna being coupled with a respective channel in said multi-channel receiver, said multi-channel radio receiver at least including a respective phase difference detector for each said selected pair of antennas, for each measurement position of a respective at least one moving antenna each respective phase difference detector measuring a phase difference between received signals produced by the antennas respective of said selected pair of antennas; and

a direction of arrival determinator, coupled with said multi-channel radio receiver and with each said at least one antenna position determinator, said direction of arrival determinator associating each phase difference measurement respective of said

selected pair antennas with a respective measurement position of said respective at least one moving antenna at which said phase difference measurement was performed, for each said selected pair of antennas and for each measurement position of said respective at least one moving antenna and respective phase difference measurement said direction of arrival determinator determining a respective set of possible directions of arrival from which said radio signal was received, said direction of arrival determinator selecting the most probable direction of arrival as the direction of arrival of said radio signal from said respective sets of possible directions of arrival.

2. The system according to claim 1, wherein each of said at least one moving antenna is mechanically coupled with a moving platform.
3. The system according to claim 2, wherein said moving platform is a rotating platform, the axis of rotation of said rotating platform is located at a known position in said reference coordinate system, the distance of said antenna from said axis of rotation is known.
4. The system according to claim 3, wherein said antenna position determinator determines the position of each of said at least one moving antenna in said reference coordinate system, according to said distance of said antenna from said axis of rotation and the angular position of said moving antenna relative to said reference direction.
5. The system according to claim 4, wherein said angular position of said moving antenna relative to said referenced directions is determined by detecting the Time Of Arrival of said radio signal modulo a complete rotation interval of said rotating platform, determining a ratio between said Time Of Arrival of said radio signal and said complete rotation interval and multiplying by 360.

6. The system according to claim 1, wherein said direction of arrival determinator determines the number of occurrences each potential direction of arrival is a member of one of the sets of possible directions, and
wherein said direction of arrival determinator determines the most probable direction according to said number of occurrences.
7. The system according to claim 6, wherein said direction of arrival determinator determines the direction exhibiting the largest number of occurrences as the direction from which said radio signal was received.
8. The system according to claim 6, wherein said direction of arrival determinator determines the most probable direction of arrival, the thus the direction of arrival of the radio signal, when the number of occurrences of one of the possible directions exceeds a predetermined threshold.
9. The system according to claim 6, wherein direction of arrival determinator produces a histogram representing the number of occurrences each one of the potential direction of arrivals in the histogram has been determined as a possible direction of arrival in one of the determined sets.
10. The system according to claim 1, wherein when said radio signal exhibits altering frequencies, said direction of arrival determinator determines the number of occurrences each potential direction is a possible direction for each frequency in the frequency alteration sequence, said direction of arrival determinator determines the most probable direction for all the frequencies in said frequency alteration sequence as the direction of arrival of said radio signal.

11. The system according to claim 1, wherein said receiver determines the frequency of said received signals and provides said frequency to said direction of arrival determinator.

12. The system according to claim 1, wherein said direction of arrival determinator determines said sets of possible directions according to

$$\Theta = \left\{ \arcsin \left(\frac{\lambda(\Delta\phi - 2\pi i)}{2\pi d} \right) \mid i \in Z \text{ and } 0 \leq i \leq \lceil n_d \rceil - 1 \right\}$$

wherein Θ represents a set of all possible directions, n_d represents the number of times the wavelength λ repeats in the instantaneous distance d between said at least two antennas, i is an integer between zero and $\lceil n_d \rceil$, and

wherein $\lceil \rceil$ represents the round-up operator.

13. The system according to claim 1 including at least three antennas, said three antennas defining a three-dimensional space, said three-dimensional space being associated with a three-dimensional reference coordinate system, and

wherein at least one of said at least three antennas is a moving antenna moving through a plurality of measurement positions, said moving antenna being mechanically coupled with moving platform.

14. The system according to claim 13, said direction of arrival determinator determining said direction of arrival in three-dimensions.

15. The system according to claim 1, wherein for each additional selected pair of antennas, said multi-channel radio receiver includes a respective additional phase difference detector, said respective additional phase difference detector measures a respective phase difference between the received signals produced by the antennas respective of said each additional selected pair, and

wherein, said direction of arrival determinator determines further a respective sets of possible directions of arrivals from which said radio signal was received according to the measured phase difference associated with each said additional selected pair of antennas.

16. A method for determining the direction of arrival of a radio signal emitted by a radio emitter, relative to a reference direction comprising the procedures of:

- determining the frequency of said radio signal;

- measuring a phase difference between received signals produced by antennas respective of each selected pair of antennas including at least one moving antenna for each measurement position of a respective at least one moving antenna, said moving antenna moving through a plurality of measurement positions in a reference coordinate system and exhibiting relative motion with respect to the other antenna, the distance between each selected pair of said at least two antennas being greater than half the wavelength of said radio signal, each antenna receiving said radio signal and producing a respective received signal;

- determining a respective set of possible directions of arrival from which said radio signal was received for each said selected pair of antennas and for each said measurement position of said respective at least one moving antenna

- determining the number of occurrences each potential direction of arrival has been determined as a possible direction of arrival of the radio signal; and

- selecting the most probable DOA as the DOA of the radio signal.

17. The method according to claim 16, wherein a histogram is produced, said histogram representing the number of occurrences each one of the potential DOAs in the histogram has been determined as a possible DOA in one of the determined sets.
18. The method according to claim 16, wherein the direction exhibiting the largest number of occurrences is determined as the direction from which said radio signal was received.
19. The method according to claim 16, wherein a possible direction with a number of occurrences, which exceeds a predetermined threshold is determined as the direction from which the radio signal was received.
20. The method according to claim 16, wherein when said radio signal exhibits frequency alteration, the number of occurrences each potential direction is a possible direction is determined for each frequency in the frequency alteration sequence.
21. The method according to claim 16, wherein for each additional selected pair of antennas, measuring a respective phase difference between the received signals produced by the antennas respective of said each additional selected pair and determining a respective set of possible directions of arrivals from which said radio signal was received further according to the measured phase difference associated with each said additional selected pair of antennas.