

System for determining a direction of arrival

The invention relates to a method of goniometric processing using a plurality of antennas forming an antenna array. This type of method makes it possible to obtain the direction of arrival of radio signals arriving on the various antennas of the antenna array.

Systems named phase or amplitude interferometry systems are known to the prior art. These systems are based on the calculation of the phase shift of a same signal received on two different antennas. However, these systems do not make it possible to obtain adequate precision and are subject to ambiguity.

It is also known that to function correctly these systems must have a distance separating the two antennas equivalent to the modulation frequency of the received signal. In order to overcome this constraint it is possible to have systems composed of a plurality of antenna pairs, with a different separation between antennas for each pair. However, the dimensions of these systems are increased and the adaptability of these systems to the bandwidth of the signal depends on the number of antenna pairs.

Systems implementing methods known by the name of high-resolution processing or beamforming are known to the prior art. However, these methods require greater computational resources and memory space than are required for phase or amplitude interferometry methods. These methods are therefore difficult to implement in systems having small dimensions or low power consumption.

The present invention therefore aims to remedy these problems by proposing a system making it possible to determine the direction of arrival of a radio signal, requiring fewer computational resources than are necessary for the implementation of high-resolution methods and a greater precision than that obtained by interferometry systems.

The present invention proposes a system for determining a direction of arrival of a radio signal comprising at least three antennas, means configured for determining at least two phase shifts, associated with various antenna pairs respectively, said phase shifts being the difference
5 between a phase of the signal received from one of the antennas of a pair and a phase of the signal received from the other antenna of the pair. The system also comprises means configured for summing at least two of the phase differences, and first means configured for determining a set of parameters respectively associated with a supposed direction of arrival,
10 based on the summation, by calculating the difference between the summation and a reference summation associated with the supposed direction of arrival. Finally, the system comprises second means configured for determining the direction of arrival as being the supposed direction of arrival associated with the parameter having the minimum value.

15 The system therefore makes it possible to determine the direction of arrival of the radio signal. Moreover, as a function of the frequency of the received signal it is possible to modify the choice of antenna pairs for which the phase shift is summed. This makes it possible to artificially change the
20 separation between the antennas.

Figure 1 exhibits the case in which the pairs of antennas are chosen in order to have an artificial separation between antennas greater than the maximum separation between two antennas.

25 Advantageously the antennas are distributed in a line.

Advantageously the antennas are evenly distributed in a circle.

30 Advantageously the system comprises at least four antennas and said means configured for determining at least two phase shifts are configured for determining phase shifts associated with various antenna pairs having one antenna in common.

The present invention also proposes a method for determining a direction of arrival of a radio signal comprising a step of determining at least two phase shifts, associated with various antenna pairs respectively, said phase shifts being the difference between a phase of the signal received from one of the antennas of a pair and a phase of the signal received from the other antenna of the pair. The method also comprises a step of summing at least two of the phase shifts, a step of determining a set of parameters respectively associated with a supposed direction of arrival, based on said summation, by calculating the difference between said summation and a reference summation associated with the supposed direction of arrival, and a second step of determining the direction of arrival as being the supposed direction of arrival associated with the parameter having the minimum value.

The invention will be better understood and other advantages will appear on reading the detailed description given by way of nonlimiting example and with reference to the figures among which:

- Figure 1 shows the choice of antenna pairs in order to extend the difference between antennas
- Figure 2 shows an embodiment of the system according to the invention
- Figure 3 shows an embodiment of part of the device 302 for determining phase shifts.

Figure 2 shows a first embodiment of the system. In this embodiment the system comprises three antennas 301-A, 301-B and 301-C. The system also comprises a device 302 for determining at least two phase shifts. Each phase shift is associated with a pair of antennas, and it corresponds to the difference between the phase of the signal received by one antenna and the phase of the signal received by the other antenna.

The system next comprises a device 303 for summing two phase shifts. This summation makes it possible to artificially change the separation between the receiving antennas by creating a virtual antenna.

Thus in the example in Figure 1, if the difference, between the phase of the signal received from the antenna 3 and the phase of the signal received from the antenna 5, is summed with the difference, between the

phase of the signal received from the antenna 3 and the phase of the signal received from the antenna 1, then the separation between the antennas is widened. This widened separation corresponds to the distance between antenna 3 and the virtual antenna 1'. This artificial increase in particular
5 makes it possible to determine the direction of arrival of signals having a lower frequency than that which can be determined without the system described in this invention. Specifically, the frequency of the signal that can be processed depends on the inverse of the distance separating the antennas (real or virtual), therefore the more this distance increases, the
10 lower this frequency becomes. The same type of result is obtained by carrying out the following summations:

- Difference between the phase of the signal received from the antenna 4 and the phase of the signal received from the antenna 1 and difference between the phase of the signal received from the antenna 4 and the phase of the signal received from the antenna 2. The summation corresponds to the distance between the antenna 4 and the virtual antenna 2'
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- Difference between the phase of the signal received from the antenna 5 and the phase of the signal received from the antenna 2 and difference between the phase of the signal received from the antenna 5 and the phase of the signal received from the antenna 3. The summation corresponds to the distance between the antenna 5 and the virtual antenna 3'
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- Difference between the phase of the signal received from the antenna 1 and the phase of the signal received from the antenna 3 and difference between the phase of the signal received from the antenna 1 and the phase of the signal received from the antenna 4. The summation corresponds to the distance between the antenna 1 and the virtual antenna 4'
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- Difference between the phase of the signal received from the antenna 2 and the phase of the signal received from the antenna 4 and difference between the phase of the signal received from the antenna 2 and the phase of the signal received from the antenna 5. The summation corresponds to the distance between the antenna 2 and the virtual antenna 5'.
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The system shown in Figure 2 also comprises a first device 304 for determining a set of parameters each associated with a supposed direction of arrival. The parameters are calculated from the difference
 5 between the summation and a reference summation associated with the supposed direction of arrival. It is for example possible to use the following relationship:

$$D = \sum_{i=1}^5 [\Delta\varphi_{mes}^i - \Delta\varphi_{ref}^i(\theta)]^2$$

In this equation $\Delta\varphi_{mes}^i$ and $\Delta\varphi_{ref}^i(\theta)$ respectively represent the
 10 measured phase shifts and the reference phase shifts. θ is the supposed direction of arrival and D represents the parameter associated with the supposed direction of arrival θ .

The system also comprises a second device 305 making it
 15 possible to determine the minimum parameter and the value of the supposed direction of arrival associated with this parameter.

Figure 3 shows an embodiment of part of the device 302 for determining phase shifts. This device comprises a first sub-device 401 making it possible to switch between the reception antennas (301-A, 301-B and 301-C) and the reception paths (402-A and 402-B). This sub-device in particular makes it possible to use a number of reception paths less than the number of reception antennas. The reception paths are made up of two analogue RF sub-devices 402-A and 402-B and of an analogue-to-digital
 25 conversion device (also known by the acronym ADC) 403. The two analogue RF sub-devices in particular make it possible to filter the signal received in the useful band, and to amplify the signal received by using low-noise amplifiers.

30 The various devices may be produced in the form of dedicated circuits (also known by the acronym ASIC for Application-Specific Integrated Circuit), in the form of an FPGA (Field-Programmable Gate Array) or in the form of a generic processor coupled with a computer program product on a

- computer-readable medium. The medium may be electronic, magnetic, optical, electromagnetic, or may be an infrared broadcasting medium. Such media include, for example, semiconductor memories (Random Access Memory RAM, Read-Only Memory ROM), tapes, diskettes or magnetic or optical disks (Compact Disk – Read Only Memory (CD-ROM), Compact Disk – Read/Write (CD-R/W) and DVD).
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CLAIMS

1. System for determining a direction of arrival of a radio signal comprising at least three antennas,

- 5 - means configured for determining at least two phase shifts, associated with various antenna pairs respectively, said phase shifts being the difference between a phase of the signal received from one of the antennas of a pair and a phase of the signal received from the other antenna of the pair,

10 said system being characterized in that it also comprises:

- means configured for calculating a phase shift between one of the antennas and a virtual antenna by summing at least two of the phase shifts;
- first means configured for determining a set of parameters respectively associated with a supposed direction of arrival, by
15 calculating the difference between said phase shift between one of the antennas and a virtual antenna, and a reference phase shift associated with the supposed direction of arrival; and
- second means configured for determining the direction of arrival
20 as being the supposed direction of arrival associated with the parameter having the minimum value.

2. System according to Claim 1, in which the antennas are distributed in a line.

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3. System according to Claim 1, in which the antennas are evenly distributed in a circle.

4. System according to any of Claims 1 to 3, comprising at least four
30 antennas and in which said means configured for determining at least two phase shifts are configured for determining phase shifts associated with various antenna pairs having one antenna in common.

5. Method for determining a direction of arrival of a radio signal comprising
- a step of determining at least two phase shifts, associated with various antenna pairs respectively, said phase shifts being the difference between a phase of the signal received from one of the antennas of a pair and a phase of the signal received from the other antenna of the pair; said method being characterized in that it also comprises:
 - a step of calculation of a phase shift between one of the antennas and a virtual antenna by summing at least two of the phase shifts;
 - a first step of determining a set of parameters respectively associated with a supposed direction of arrival, by calculating the difference between said phase shift between one of the antennas and a virtual antenna, and a reference phase shift associated with the supposed direction of arrival; and
 - a second step of determining the direction of arrival as being the supposed direction of arrival associated with the parameter having the minimum value.