(12) **EUROPEAN PATENT SPECIFICATION**

(54) **METHOD FOR DETERMINING THE TIMING OF THE RECEIPT OF A RADIO MESSAGE**

VERFAHREN ZUR BESTIMMUNG DER LAUFZEIT DER AUFNAHME EINER FUNKRUFNACHRICHT

PROCÉDÉ DE DÉTERMINATION DE SYNCHRONISATION DE RÉCEPTION DE MESSAGE RADIO

(72) Inventors:
• **WILLART, Nils
135 34 Tyresö (SE)**
• **JOHANSSON, Bengt
413 24 Göteborg (SE)**

• **BERGSTRÖM, Anders
182 65 Djursholm (SE)**

(74) Representative: **Noréns Patentbyrå AB
Box 10198
100 55 Stockholm (SE)**

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**Description**

[0001] The present invention relates to a method for determining the time of receipt of a radio message, especially an AIS (Automatic Identification System) signal sent from a transmitter to a receiver located in proximity to the transmitter. Furthermore, the invention relates to a receiver, especially an AIS receiver, for receiving such a signal.

[0002] For example, in the shipping and aviation fields, the standardized communication system AIS is widely used for local communication between, for instance, moving vessels or between moving vessels and fixed installations, such as a port or a lighthouse. See for example "Recommendation ITU-R M.1371-4", published in 2010 by the International Telecommunication Union.

[0003] According to this system, a set of digitally coded, predefined messages of different types can be used by, for example, a vessel for, among other things, informing about its current position and speed to recipients located in the local geographical neighbourhood of the vessel in question. The system is self-organizing in the sense that the participating transmitters divide their respective transmission over a predetermined periodically repeated time window of certain length, so that each transmitter uses a particular part of the time window for transmission.

[0004] AIS systems often have low security, in the sense that it is difficult to verify if the contents of the data being sent, such as the position of the transmitter, is accurate and consistent with the real situation. This means that transmitters wishing to participate are expected to follow the AIS standard and to transmit accurate information, and that only simple steps to verify the received information is built into the system. For example, too large timing errors for transmitted signals are not allowed.

[0005] It would be desirable to provide an improved control ability of a receiver with respect to the information transmitted by a vessel, such as the vessel position, speed and heading. It would also be desirable to be able to detect whether a particular AIS signal is emitted by one and the same transmitter.

[0006] It is known to use directional antennas for measuring the direction to a radio transmitter, in order to verify the transmitter position. This is costly and gives relatively poor precision.

[0007] It would be further desirable to provide a simple way for a vessel, whose local clock falls out of sync with the other transmitting vessels, to re-synchronize its local clock. Specifically, it would be desirable to provide a so-called secondary synchronization, which can be used as an alternative to the AIS standard supported synchronization process when the latter for some reason is not available.

[0008] It would also be desirable to provide a way for two or more transmitters/receivers to be able to jointly agree on a specific time definition, which is secret among the transmitter/receiver, without any other recipients also receiving information regarding such information.

[0009] These objectives should preferably be met using existing AIS standard equipment, in a cost-effective manner and with only a minimum of necessary modifications to existing AIS equipment.

[0010] In the field of mobile telephony, US 2007/0276616 A1 discloses a method for accurate time of arrival determination using a correlation between a previously known received signal element with a comparison signal.

[0011] The present invention solves the above described problems.

[0012] Thus, the invention relates to a method for determining the time of receipt by a radio receiver of a binary coded AIS message, sent by a transmitter in the form of a first signal which is a modulated radio signal, whereby the first signal is received by the receiver using an antenna so that a second signal in the form of an analogue electrical signal is achieved, which second signal is sampled and optionally demodulated, which sampling and demodulation can be performed in any order, which sampling is performed using an AD converter, so that a digitally stored third signal in the form of a sampled and optionally demodulated signal is achieved, wherein the data content of the message is determined from the third signal as a stream of data bits, which stream of data bits comprises a predetermined signal element whose time of receipt is determined, and wherein the time of receipt of the message is determined based on the timing of the predetermined signal element, which method is characterised in that a digitally stored, constructed comparison signal is generated on the basis of said stream of data bits, so that the constructed comparison signal is constructed to correspond to the third signal, in that an optimum value is determined for a time variable, which time variable indicates a time position of the constructed comparison signal relative to the third signal and for which optimum value a correlation between the constructed comparison signal and the third signal is maximal, and in that the optimum value of the time variable is used to correct the determination of the time of receipt of the predetermined signal element.

[0013] Moreover, the invention relates to a receiving device arranged to receive a binary coded AIS message, sent by a transmitter in the form of a first signal which is a modulated radio signal, which receiving device comprises an antenna arranged to receive the first signal and thereby to achieve a second signal in the form of an analogue electrical signal, an AD converter and an optional demodulation device, which AD converter and optional demodulation device are arranged to sample and possibly demodulate the said analogue signal, which sampling and demodulation can be performed in any order, and thereby to achieve a digitally stored third signal in the form of a sampled and optionally demodulated signal, which receiving device furthermore comprises a decoding device, arranged to decode the third signal and thereby to achieve the data content of the message as a stream of data bits, which stream of data bits comprises a pre-

determined signal element whose time of receipt is determined, and wherein the receiving device is arranged to determine the time of receipt of the message based on the timing of the predetermined signal element, which receiving device is characterised in that the receiving device comprises a timing determination device arranged to determine the time of receipt of the predetermined signal element, in that the timing determination device is arranged to generate a digitally stored, constructed comparison signal on the basis of said stream of data bits, so that the constructed comparison signal is constructed to correspond to the third signal, in that the timing determination device is arranged to determine an optimum value for a time variable, which time variable indicates a time position of the constructed comparison signal relative to the third signal and for which optimum value a correlation between the constructed comparison signal and the third signal is maximal, and in that the timing determination device is arranged to correct the said time determination of the predetermined signal element using the optimum value of the time variable.

[0014] In the following, the invention will be described in detail, with reference to exemplary embodiments of the invention and to the accompanying drawings, in which:

Figure 1 shows the structure of a general AIS message;
Figure 2 shows a graph representing a gauss filtered, digitally encoded, exemplifying AIS message;
Figure 3 is an overview diagram illustrating a system according to the invention which can be used in a method according to a first embodiment of the invention;
Figure 4 illustrates the transmitter functionality of an AIS equipment according to the invention;
Figures 5a and 5b illustrate two different variants of the receiver functionality in an AIS equipment according to the invention;
Figure 6 is an overview diagram illustrating a system according to the invention which can be used in a method according to a second embodiment of the invention; and
Figures 7a-7d are respective graphs illustrating a signal processing in accordance with the invention.

[0015] AIS is an example of a time-distributed messaging system, under which standardized binary coded radio messages can be sent directly between geographically proximate connected units, without the need for a common central unit via which messages need to be sent. The system is based on AIS-connected transmitters periodically or aperiodically emitting different types of standardized messages, and on that the different transmitters comprised in the system themselves distribute the available bandwidth of each transmission time period between them.

[0016] Figure 3 shows two pieces of equipment 330, 340, permanently installed on land, for receiving and possibly transmitting AIS messages, as well as moving vessels in the form of boats 310, 320 arranged off a shore 300, on the water, which vessels comprise respective equipment for transmitting and receiving AIS messages. AIS messages in the form of radio signals 311, 321 are illustrated schematically.

[0017] As is shown in figure 3, at least AIS transmitters 310 and 320 transmit to all AIS receivers that are within the receipt range of the respective AIS transmitter in question. Although all connected devices 310, 320, 330, 340 are not necessarily of the same standardized type, they will, when brought together geographically, establish a self-organizing communication between them based on time division over a certain transmission period. How this works falls within the AIS standard and is conventional as such.

[0018] It is understood that the fixed and mobile units 310, 320, 330, 340 illustrated in Figure 3 may equally well be other types of fixed devices, such as a permanently installed transponder at an airport, and other types of moving vessels, such as aircraft or wheeled vehicles.

[0019] Different types of AIS messages are intended to use for different types of information, examples comprising information regarding the current position, speed, yaw rate, destination, draught and so on, for the connected device. Different types of AIS messages are transmitted according to the AIS standard at different intervals and using different power, depending inter alia on the type of transmitter.

[0020] These and other aspects of the AIS system are controlled, among others, in the recommendation ITU-R M-1371 (above). More information is also present in the documentation provided by the International Maritime Organization (IMO).

[0021] Figure 1 illustrates the general data structure for an AIS message, comprising the following binary coded fields. A "bit" is a "one" or a "zero".

- **Preamble:** an initial sequence of 24 bits. May, for instance, be alternatingly "0" and "1", but with at least one trailing "0".

- **Start flag** and **End flag:** both comprise 8 bits and serve as delimiters for the AIS message. May for instance be 8 bits that are all "1".

- **Data:** 168 bits, apart from the information to be transmitted comprising the message identifier **MSG ID,** the sender identifier **User ID** and the field **Communication state.**

- **FCS:** a 16 bit checksum calculated based upon the contents of the field Data, and the purpose of which is to be able to verify the integrity of the AIS message contents.

- **Buffer:** 24 bits that may be used in predefined ways

in order to communicate information about, for instance, sender distance and signal quality.

[0022] Thus, of the total length of 256 bits, a certain part of the field Data is used for the actual transfer of parameter values, while some initial fields, such as Preamble and Start Flag, comprise previously determined information.

[0023] Figure 4 illustrates the functional structure concerning transmission of an AIS device 400 according to a preferred embodiment, comprising means for assembling and periodically transmitting AIS messages of at least one predetermined type, which AIS messages are readable by a receiving device for AIS messages. It is preferable that the transmitting device 400 follows the specifications of a particular AIS type (such as "Class A", "Class B", base stations, AtoN (Aids to Navigation), SART (Search and Rescue Transmitter), and so on), and as such is capable of sending a certain set of different AIS message types at certain intervals.

[0024] The device 400 comprises a sensor 401, arranged to detect that an AIS message of the certain predetermined type, or possibly other types, is to be sent, such as based upon the time frame allotted to the transmission device 400 in the distributed system, or based upon CSTDMA.

[0025] Further, the transmitting device 400 comprises a digital message assembly means 402, arranged to assemble, digitally store and calculate a checksum for an AIS message of said predetermined, and any other, types. The message assembly means 402 receives the information to be transmitted in the AIS message inter alia, or at least, from a data source 403, which can contain information such as geographic position, transmitter identity and so on.

[0026] An example of the message produced and stored by the message assembly means 402 is illustrated in Figure 2, as the sequence of binary "ones" and "zeroes" shown at the bottom of the figure. In Figure 2, the message is abbreviated for reasons of clarity.

[0027] In a preferred embodiment, the transmitting device 400 further comprises a filtering means 404, arranged to produce a filtered signal based on said digitally stored binary digital signal. One example of such a filtered signal is shown in Figure 2, as the upper curve. The binary "ones" and "zeroes" are shown in figure 2 next to the filtered signal, and it is clear from figure 2 that a binary "one" corresponds to a higher signal value in the curve, and vice versa for a binary "zero", which corresponds to a lower signal value in the curve. As illustrated in Figure 2, the message does not follow the format regarding the number of bits in different fields illustrated in figure 1.

[0028] As is clear from figure 2, the filtered curve is not a pure step function, but a filtered version of a step function corresponding to the number sequence shown below the curve in the figure. This filtering causes the characteristic appearance of the curve. Examples of preferred filters comprise filtering using a gauss filter, as in conventional GMSK modulation (Gaussian Minimum Shift Keying). It is preferred that the obtained filtered curve is analogue, whereby the filter preferably can be an analogue filter, but it may also be digitally encoded, in which case the filter is digital.

[0029] The filtered curve is fed to a modulating device 405, which modulates, preferably frequency modulates, the filtered signal on a carrier wave, which is then amplified and fed to an antenna 406, which in turn transmits the AIS signal as a radio signal 420.

[0030] It is preferre3d that all steps 401-406 constitute software or hardware implemented parts, respectively, of one and the same computer equipment, which in that case comprises or constitutes the device 400.

[0031] Figure 5a schematically illustrates the receiving functionality of an AIS device 500 according to the present invention, arranged to determine the time of receipt by the AIS device 500 of an AIS message sent by a transmitter similar to the one described above. An antenna 501 is arranged to receive an incoming radio signal 520 encoding an AIS message, so that an analogue electrical signal is achieved. The radio signal, which is a modulated radio signal, is composed of a carrier wave on which a data signal is modulated, preferably frequency modulated. The radio signal is a first signal of the present invention.

[0032] The received analogue signal constitutes a second signal of the present invention. This second signal is sampled, and possibly also demodulated. The thus produced, sampled and optionally demodulated signal constitutes a third signal of the invention. In case the signal is both sampled and demodulated, the sampling and demodulation may be performed in any order, see below.

[0033] According to the present exemplifying embodiment, the second signal is demodulated and sampled, which sampling is performed using an AD converter 503, so that a digitally stored, sampled and demodulated signal is achieved, corresponding to the demodulated analogue signal. The AD converter 503 has a sampling frequency of at least 10 kHz, preferably at least 100 kHz. Alternatively, the sampling frequency is at least 10 times as high as the bit rate per second of the received signal, which bit rate in the case of an AIS message is 9600 Hz.

[0034] Figure 5a shows a demodulation device 502, which is arranged to accept said analogue electrical signal and to demodulate this signal so that a demodulated analogue signal is achieved, and is fed to the AD converter 503. This demodulated analogue signal resembles the upper curve in figure 2 as regards its appearance, but also comprises some components in the form of noise and any additional filtering effects from the transmitter as well as the receiver.

[0035] Figure 5b is identical to figure 5a, but illustrating an alternative configuration, wherein the AD converter 503 is arranged to sample the incoming frequency modulated, analogue signal from the antenna 501, so that a digital version of this signal is achieved, and wherein the

demodulating device 502 is digital, and performs demodulation in the digital domain.

[0036] It is also understood that in case the second signal is sampled directly, either a digital demodulation can be performed, alternatively the information can be directly extracted from the sampled signal without any particular demodulation.

[0037] The demodulated digital signal is then fed to a decoding device 504, arranged to determine the AIS message data content based on the demodulated signal, as a stream of data bits similar to the lower number sequence in figure 2. This decoding is done in a conventional manner. The decoding device 504 is preferably an AIS standard modem, which modem may also comprise, for example, the demodulating device 502.

[0038] The decoding device 504 is arranged to, after decoding, make the received message available via an interface 505, such as a graphic display or a digital communication interface for the publication of the message for reading of external software modules.

[0039] According to the invention, a predetermined signal element has been defined beforehand which it is known that said stream of data bits comprises. Preferred examples of such predetermined signal elements are the front edge or the trailing edge of the field "Start flag", illustrated in figure 1 and in figure 2. For example, at the front edge, it may be known in advance that one "zero" is followed by a series of eight "ones". At the trailing flank, it may be known in advance that a series of eight "ones" is followed by one "zero". A signal element of the latter type is indicated by an arrow 201 in figure 2. It is preferred that the predetermined signal element in a corresponding way is constituted by a predetermined position in a number of bits of the AIS message whose data content is known in advance, and which preferably comprises either a series of "zeroes" or a series of "ones" of a pre-known length, which is followed by a change from "0" to "1" or from "1" to "0". This provides a simple and unambiguously identifiable upward or downward flank in the demodulated signal. It is especially preferred, in particular in AIS applications, that the signal element is constituted by the final bit in a previously known series of bits that each is either "0" or "1", and which is followed by a switch to "1" or "0", respectively. In particular, the end of, in other words the trailing edge of, the field "Start flag" in AIS messages is useful.

[0040] According to the invention, it is the time of receipt of said signal element that is determined, and the time of receipt of the message is then determined based on the timing of the predetermined signal element by the position of the predetermined signal element in the message being known in advance.

[0041] This is accomplished by a digitally stored constructed first comparison signal being generated by a timing determination device 508 and on the basis of the stream of data bits, in other words the data content in the received AIS message, so that the constructed comparison signal is constructed to correspond to either the received frequency modulated signal before or, preferably, after demodulation. This comparison signal must always correspond to the sampled signal, but in case the AD converter 503 is arranged upstream of the demodulation device 502 it may be the sampled signal before or after demodulation that the comparison signal is to be constructed to correspond to. In the case in which the signal received by the antenna, before modulation by the transmitter, is filtered by a particular filter, it is preferred that the comparison signal is constructed by, in a corresponding manner, filtering a digital signal representing the data content using a filter with essentially the same properties as the said certain filter, for example a gauss filter according to the above.

[0042] As is clear from figures 5a and 5b, the decoded binary data in the AIS message is fed from the decoding device 504 to the timing determination device 508. In addition, the sampled signal, or alternatively the sampled and demodulated signal, as well as interrupt signals (see below), are fed to the timing determination device 508.

[0043] In the present context, that the comparison signal is "constructed to correspond to" the received signal means that the timing determination device 508 digitally synthesizes a signal curve, by data processing of the digital contents of the received AIS message, such as in terms of binary "ones" and "zeroes", in a way that simulates or corresponds to the signal processing in the transmitter that gave rise to the sent and then received, modulated radio signal 520. In other words, the decoded binary data in the AIS message is used to simulate the sampled and optionally demodulated signal received by the timing determination device 508, using known characteristics of the transmitter regarding how the transmitter creates the transmitted radio signal.

[0044] In the example illustrated in figures 4, 5a and 5b, this indicates that a gauss filtered curve of the type illustrated at the top in figure 2 is achieved, corresponding to the bit sequence in the AIS message analysed in the decoding device 504. Thus, in this example, the signal having been received by the antenna 501, before modulation by the transmitter, has been filtered by a particular filter which then also is applied to the constructed signal.

[0045] Thereafter, an optimum value for a time variable is determined by the timing determination device 508, which time variable specifies a position or displacement of the constructed comparison signal on the time scale relative to said sampled and possibly demodulated signal, and for which optimum value a correlation between the constructed comparison signal and the sampled signal is maximal. In the following, the sampled and optionally demodulated signal is denoted the "sampled signal", for reasons of simplicity.

[0046] Herein, the term "correlation" refers to a comparison operation performed between the two signals for individual points in time, and which is a measure of the total conformity and/or covariance of the signals as seen over a certain time interval.

[0047] In other words, the constructed comparison sig-

nal is oriented by a certain time scale displacement relative to the corresponding sampled signal, after which a correlation between the signals is calculated, and the displacement that maximizes the correlation is the optimum value for the time variable.

**[0048]** The correlation can for example be calculated as:

$$C_j = k \sum_{i=T_0}^{T_1} (S(i)J(i+j))$$

where

j = the said time constant
$C_j$ = the correlation for time constant = j,
k = a constant,
{$T_0$, $T_0$} = the time interval in question,
S(i) = the sampled signal curve in point (i), and
J(i) = the constructed comparison signal curve in point (i).

**[0049]** {$T_0$, $T_0$} may cover the whole time overlap of the signal curves, alternatively only a shorter test time interval.

**[0050]** It is realized that the correlation, in a corresponding manner, can be calculated over a continuous time interval, rather than for discrete time points.

**[0051]** Hence, the value for j which maximizes $C_j$ is calculated.

**[0052]** According to a preferred embodiment, the optimum value for the time variable is calculated by calculating the correlation for several values of the time variable, and then searching for the global maximum for the correlation as a function of the time variable. Numerically, this can for example be performed by first determining an initial temporal relative orientation of the two signals, which may be based on empirically derived values for delays in the receiver 500. Then, the correlation may be calculated for a number of values of the time variable shifted forwards or backwards relative to the original time orientation, so that a rough approximation of a correlation function C(j) is achieved, by means of which a coarse value for the optimum time variable can be determined. Then, the correlation may be calculated for shorter intervals of the time variable in an interval around the said rough value, in order to achieve a more accurate value for the maximum. This can be repeated several times, and finally the correlation derivative can be calculated, and the maximum may be determined as the value of the time variable for which the derivative function intersects 0. This intersection may for example be calculated by means of linear interpolation. All these calculations are done in a microprocessor in the receiver 500, and on the initiative of the timing determination device 508.

**[0053]** Then, the thus determined optimum value for the time variable is used for correcting the determination of the time of receipt of the predetermined signal element. Information regarding the corrected timing is then published by the timing determination device 508 via the interface 505.

**[0054]** According to a preferred embodiment, the decoding device 504 is arranged to detect the receipt of the above discussed predetermined signal element, and at such a detection to report the receipt to the timing determination device 508. In this case, it may be a time determination of the receipt by the decoding device 504 of the predetermined signal element which is corrected by the above described time variable.

**[0055]** According to a further preferred embodiment, all relevant delays in the receiver are measured before the AIS message is received, comprising the delay in the demodulation device 502, the AD converter 503 and the decoding device 504. Then, those of said delays that affect such timing information which is reached by the timing determination device 508 and that relate to the receipt of the predetermined signal element, and/or those of said delays that occur before a signal indicating that the predetermined signal element has been received reaches the timing determination device 508, are used for adjusting the timing determination of the predetermined signal element in addition to the adjustment using the optimum time variable. Such delays are generally consistent, predictable, and can therefore be determined in advance. Examples comprise delays in the AD converter 503 itself.

**[0056]** According to one preferred embodiment, in addition to a filtering intended to simulate a filter that is applied by the transmitter before modulation, such as the above described gauss filtration, the constructed comparison signal may also be subjected to a filtration using a filter before computing the said correlations, so that deviations of the sampled signal that occur due to the previously known analogue frequency and/or phase response are simulated before sampling using said filter. Such a filter may for instance be constituted by a suitable FIR filter.

**[0057]** The sampled signal to be correlated with the comparison signal may be fed to the timing determination device 508 from the decoding device 504, but it is preferred that it is fed to the timing determination device 508 directly from the demodulation device 502 or the AD converter 503. What is important is that information concerning the time of receipt of the predetermined signal element is made known to the timing determination device 508.

**[0058]** The receiver includes a clock 507 which provides the timing determination device 508 with the current time. According to a preferred embodiment, the AD converter 503 sends out at least one interrupt signal to indicate a certain sampling time. The interrupt signal is detected, directly or via for example the decoding device 504, by the timing determination device 508, and the sending of the interrupt signal is timed by the clock 507. In this case, the above described time of receipt of the

predetermined signal element is based on the time-determined emission of the said interrupt signal, by means of the sending time of the interrupt signal being compared to a certain temporal position of the sampled signal. It is preferred that the interrupt signal whose sending is related to the sampled signal is the interrupt signal which is sent when, or in connection to when, the predetermined signal element was received. As described above, various delays of the demodulating device 502, the AD converter 503, the decoding device 504 and so on, that are previously known, may be compensated for in an appropriate way in order to determine which interrupt signal is sent when the predetermined signal element was received.

[0059] According to a preferred embodiment, the AD converter 503 sends a plurality of interrupt signals at predetermined time intervals, preferably one interrupt signal for each sampling point. In this case, the sending is time-determined using several such interrupt signals consecutively sent out by the clock 507, after which each one of the points in time for the receipt of such interrupt signals is adjusted using said previously known time intervals, in order to estimate the time of sending of a certain single interrupt signal, such as the interrupt signal at which the predetermined signal element was received. The thus adjusted time determinations are averaged, so that an averaged time of sending of the certain single interrupt signal is achieved. Finally, the determination of the time of receipt of the predetermined signal element is based on said averaged point in time of the sending of the certain single interrupt signal, by relating the certain single interrupt signal to a specific position on the time scale of the sampled signal.

[0060] For example, the interrupt signal at which the predetermined signal element was received may constitute the certain single interrupt signal, and a sequence of interrupt signals which is then detected by the timing determination device 508 may be used to calculate a more accurate value of the sending time of the certain interrupt signal as follows:

$$T_{med} = K + \frac{1}{m} \sum_{i=0}^{m-1} \left( T_{CLK}(i) - \frac{1}{F_s} \right)$$

where

T_med = the time averaged value for the receipt of the certain single interrupt signal,
K = an optional adjusting time constant for taking into consideration delays in the receiver 500,
m = the total number of interrupt signals to be used for the calculation of the average value,
$T_{CLK}(i)$ = the time of the clock 507 when the interrupt signal with number i from the certain interrupt signal is detected by the timing determination device 508, and

$F_s$ = the samplings frequency.

[0061] m is preferably a number of samplings corresponding to at least 10 bits in the message signal, alternatively at least 100 samplings.

[0062] Such a method provides a highly accurate value for the receipt, and thus also the sending of a certain single interrupt signal (in this example the one when the predetermined signal element was received). Thereby, a precisely defined time reference for the sampled signal is achieved, wherein the above described time determination using the constructed signal also becomes highly accurate, in the corresponding way.

[0063] It is further preferred that the clock 507 comprises a local oscillator, which is periodically synchronized to the time information in a received GPS signal (Global Positioning System) 530, which is received through an antenna 506. The extraction of a time signal from the GPS signal 530 is conventional as such. The present inventors have discovered that if the local oscillator consists of a per se conventional crystal oscillator, which is less expensive than, say, an atomic clock, and in case the oscillator is periodically synchronized using GPS signal timing, adequate results are achieved with regard to the timing of the received AIS message. It is thus preferred not to use an atomic clock.

[0064] It is preferred that the clock oscillator 507 is periodically synchronized using the time information of the GPS signal 530, preferably at least every minute, more preferably at least every ten seconds, more preferably at least every second. It is preferred that the clock 507 is sufficiently precise to always have a sense of time that is correct to the precision of at the most 100 ns for such synchronization periods.

[0065] Using a method according to the present invention, the time of receipt of a message comprising a predetermined signal element can be determined with great accuracy. Also, the receipt of single messages can be timed precisely.

[0066] In particular, this applies to AIS messages. As an AIS receiver typically already comprises modules 501, 502, 503, 504 and 506, the timing determination device 508 may, at low cost, be added to the existing equipment, for example in the form of a software module arranged to be executed on the same computer that already executes for instance software constituting the decoding device 504. This way, the receipt of up to 2250 messages per minute may be timed within the scope of the existing AIS system and without significant investment in new hardware.

[0067] In the following, a number of applications are described in which such accurate timing can be used.

[0068] Figure 3 illustrates a first example, in which the position of the vessel 310 is determined by triangulation between the respective times of receipt of the message signal by at least three different receivers, such as AIS receivers 320, 330, 340. The clocks in each of these receivers 320, 330, 340 have been synchronized ahead of

time, to one and the same common view of the current time, preferably by means of all three being of the above described GPS-synchronized type, thereby sharing the same time reference.

**[0069]** All three receivers 320, 330, 340 receive the AIS radio signal A, B, C from the transmitter 310, but at different times. Each of the receivers 320, 330, 340 measures the time of receipt of the same predetermined signal element of the received signal, and a location of the transmitter 310 is then determined by triangulation based on the respective location of the three recipients, which is known in advance, in combination with differences in the respective time of receipt of the said signal element. The triangulation calculations themselves may be performed by a central computer 350, which is connected to the receivers 320, 330, 340. Any movable participating vessels 320, such as boats, trucks or helicopters, may report their current position through an as such conventional wireless data link 322.

**[0070]** Using such a process, the present inventors have noted that accuracies of as little as a few hundred meters have been achieved regarding the position determination of an AIS transmitter 310 at an SNR (Signal to Noise Ratio) of 10 dB, which is sufficient to in practice be able to verify the accuracy of, for example, the reported location of the AIS transmitter 310 as reported by the transmitter 310 itself.

**[0071]** According to a preferred embodiment, at least one AIS message being sent by the AIS transmitter 310 is tapped, so that a stated position for the AIS transmitter can be obtained. In addition, AIS information that allows the time of sending of a specific future AIS message to be predicted is preferably tapped, for instance using information about where in the AIS time window a specific AIS message is periodically sent from the AIS transmitter 310 during normal operation. Then the receipt of the certain future AIS message from the AIS transmitter 310 in question is tapped and timed, and the position of the AIS transmitter 310 is triangulated as described above, based on the receipt of the certain AIS message in question.

**[0072]** Thereafter, the calculated position of the AIS transmitter 310, and/or a heading and/or a velocity, as calculated based on several successive calculations performed by the location of the AIS transmitter 310, may be compared with a position and/or a heading and/or a velocity of AIS transmitter 310 as stated in an AIS message sent by the AIS transmitter 310. In the case in which locations and/or headings and/or velocities are pairwise different by more than a respective predetermined value, an alarm signal is emitted via an alarm device 351, which in figure 3 is illustrated symbolically.

**[0073]** Figure 6 illustrates a further example of an application of the method described above for precise timing of an AIS message, with at least two transmitter/receiver apparatuses 610, 620, such as AIS equipment that can be installed on fixed and/or movable objects, both including a respective GPS synchronized clock according to the above, and both being able to send out radio signals 611, 621, such as AIS messages. In this case, the position of a transmitter 610 relative to a receiver 620 is known in advance by the receiver 620, whereby the transmitter 610 transmits a radio message including a predetermined signal element, such as an AIS message, to the receiver 620. Thereby, the receiver 620 can determine the timing of the receipt of the transmitted signal with high accuracy, using a method according to the invention. After correcting for the signal delay between the transmitter 610 and the receiver 620, based on said known relative distances, a precise timing of the transmitter's 610 sending of the message is achieved by the receiver 20. Thus, a common point in time can be synchronized between the transmitter 610 and receiver 620, based upon the commonly known timing of the sending by the transmitter 610 of the message signal.

**[0074]** Such a time synchronization between two devices 610, 620 can be used, for instance, to agree on a common secret sense of time, without any other nearby devices being able to gain knowledge about such a sense of time. The sense of time can for example be used to agree ahead of time on the timing of a change of carrier frequency for secret information, or the like.

**[0075]** In both of the applications described in connection with Figures 3 and 6, there are additional benefits of adding another layer of authentication based on a fingerprint regarding the transmitter 310, 610.

**[0076]** For example, in Figure 3, the verification of the position, speed and/or heading of the transmitter 310 may be combined with a verification of such fingerprint, so that the combined verification becomes very safe. For example, the fingerprint of one AIS message may be compared with that of a later sent AIS message, and verification can be done by examining whether or not the fingerprints are identical. Alternatively, a detected fingerprint may be compared to a previously known fingerprint, based on knowledge of the type of AIS transmitter equipment or the like. Moreover, it can be verified that the same radio signal is accessed by all three receivers 320, 330, 340.

**[0077]** In Figure 6, a verification of a previously known fingerprint of the transmitter 610 is used to ensure that the transmitter 610 really is the expected one.

**[0078]** Herein, a "fingerprint" refers to a characteristic of the radio signal depending on the characteristics of the transmitter itself, such as a previously known deviation from an ideal signal depending on signal processing in the transmitter. Examples include predictable variations in timing inaccuracies over an AIS period, characteristic pulse shapes at ramp-ups or ramp-downs and the resulting GMSK signature of the sender.

**[0079]** In the following, an embodiment is presented in order to provide a thorough understanding of the invention, in which example a received AIS signal is simulated, and then compared to a constructed signal of the present invention.

**[0080]** First, a bit stream is created, consisting of the fields "Preamble" and "Start flag", above, and the random

bits corresponding to the rest of the AIS message. In total, the bit stream comprises 250 bits, which may then form the basis for a simulation of a sending of an AIS message with bit rate 9600 bits/sec.

**[0081]** The digital bit stream is graphically illustrated in the lower curve of figure 7a. The bit stream then passes to a conventional digital gauss filter, resulting in the upper curve of figure 7a.

**[0082]** To simulate the interference of the signal arising under normal operating conditions in reality, the resulting signal is then degraded using two consecutive first-order low-pass filters with cut-off frequencies around 5 kHz, arranged to simulate the transmitter's signal characteristics. Finally, a white noise is added, with the same root mean square as the signal itself. The resulting curve is illustrated in figure 7b.

**[0083]** A simulated sampling, with a sampling rate of 192 kHz, is then carried out, wherein a sampled signal according to the invention is achieved.

**[0084]** A comparison signal is constructed by the upper curve in figure 7a being subjected to the same low pass filter as the simulated signal, but without white noise.

**[0085]** Next, the sampled and the constructed signals are correlated for different values of a time variable that displace them on the time scale relative to each other. The calculated correlation function of the time variable is illustrated in figure 7c.

**[0086]** Figure 7D is an enlargement of the curve 701 shown in figure 7c around the global maximum of the curve. In Figure 7d, both the actual curve 701 and its derivative 702 are shown. The y-axis indicates the value of the derivative. As is evident in figure 7d, the optimum time variable 700 is selected as the value 703 that maximizes the correlation 701, and which is finally calculated by linear interpolation of the derivative function 702.

**[0087]** Such a simulation of real conditions gives the following repeatability regarding the timing for different relative noise levels:

> Signal level = Noise level: about 90% fall within ±5.00 μs
> Signal level = 10 x Noise level: about 90% fall within ±0.50 μs
> Signal level = 100 x Noise level: about 90% fall within ±0.05 μs

**[0088]** Above, preferred embodiments have been described. However, it is apparent to the person skilled in the art that many modifications can be made to the described embodiments without departing from the basic idea of the invention.

**[0089]** For example, the inventive concept is also applicable to other types of radio messages than AIS messages.

**[0090]** Furthermore, other types of previously known or detected fingerprints regarding the transmitter's signal characteristics may be used to increase security.

**[0091]** Thus, the invention is not to be limited to the embodiments described, but can be varied within the scope of the enclosed claims.

**Claims**

1. Method for determining the time of receipt by a radio receiver (320,330,340;500;620) of a binary coded AIS (Automatic Identification System) message, sent by a transmitter (310;400;610) in the form of a first signal which is a modulated radio signal (520), whereby the first signal is received by the receiver using an antenna (501) resulting in a second signal in the form of an analogue electrical signal , which second signal is sampled, which sampling can be performed in any order in relation to any demodulation of the second signal, which sampling is performed using an AD converter (503), resulting in a digitally stored third signal in the form of a sampled signal, wherein the data content of the message is determined from the third signal as a stream of data bits, which stream of data bits comprises a predetermined signal element whose time of receipt is determined, and wherein the time of receipt of the message is determined based on the timing of the predetermined signal element, **characterised in that** a digital comparison signal is constructed on the basis of said stream of data bits, so that the constructed comparison signal is constructed to simulate the third signal, **in that** an optimum value is determined for a time variable, which time variable indicates a time position of the constructed comparison signal relative to the third signal and for which optimum value a correlation between the constructed comparison signal and the third signal is maximal, and **in that** the optimum value of the time variable is used to correct the determination of the time of receipt of the predetermined signal element.

2. Method according to claim 1, **characterised in that** the third signal is obtained by analogue modulation of the second signal, followed by sampling of the resulting correspondingly modulated signal.

3. Method according to claim 1 or 2, **characterised in that** the first signal, before modulation by the sender (310;400;610), is filtered using a certain filter, and **in that** the comparison signal is constructed by, in a corresponding way, filtering a digital signal representing the said data content using a filter with essentially the same properties as the said certain filter.

4. Method according to claim 1 or 2, **characterised in that** the constructed comparison signal, before calculation of the said correlations, is filtered using a filter so that deviations of the third signal, arising as a consequence of the analogue frequency and/or phase response of the receiver

(320,330,340;500;620) before sampling is simulated using said filter.

5. Method according to any one of the preceding claims, **characterised in that** the AD converter (503) sends out at least one interrupt signal for marking a certain sampling time point, **in that** the time of emission of such interrupt signal is determined using a clock (507) in the receiver, and **in that** the time determination of the receipt of the said predetermined signal element is based upon the timed sending out of the said interrupt signal by relating the sending out of the interrupt signal to a certain time position of the third signal.

6. Method according to claim 5, **characterised** i n that the AD converter (503) sends out a number of interrupt signals at predetermined time intervals, whereof the time of the sending out of several such respective interrupt signals is determined using the said clock (507) and are adjusted using the said time interval in order to estimate the point in time of the sending out of a certain interrupt signal, in that these adjusted timing determinations are averaged so that an averaged timing determination of the sending out of the certain interrupt signal is obtained, in that the timing determination of the receipt of thee said predetermined signal element is based upon the averaged timing determination of the sending out of the certain interrupt signal by relating the certain interrupt signal to a certain time position of the sampled signal.

7. Method according to claim 5 or 6, **characterised in that** the clock (507) comprises a local oscillator, which regularly is synchronized to the time information in a received GPS (Global Positioning System) signal (530).

8. Method according to any one of the preceding claims, **characterised in that** the location of the sender (310;400;610) is known by the receiver (320,330,340;500;620), and **in that** a common point in time is synchronized between the sender and the receiver by the receiver correcting the timing determination of the receipt of the said predetermined signal element for the time it takes for the radio signal (520) to travel between the sender and the receiver, based upon the distance between the locations of the sender and the receiver, respectively.

9. Method according to claim 7, **characterised in that** at least three receivers (320,330,340), the respective clocks (507) of which have been previously synchronized, receive one and the same radio signal (520) from a certain sender (310), **in that** each of the receivers determine the timing of the receipt of the same predetermined signal element of the received signal, and **in that** a location of the sender is determined by triangulation, by a central unit (350) in communication with said at least three receivers, based upon the respective location of the three receivers in combination with differences in the respective point in time for the respective receipt of the said signal element.

10. Method according to claim 9, **characterised in that** the calculated location for the sender (310;400;610), and/or a heading and/or a velocity which has been calculated based upon several consecutive calculations of the location of the sender, is compared to a location and/or a heading and/or a velocity for the sender which is stated in an AIS (Automatic Identification System) message which is sent out from the sender, and **in that** a warning signal is emitted in case the two positions and/or headings and/or velocities are pairwise different by more than a respective predetermined value.

11. Receiving device (320,330,340;500;620) arranged to receive a binary coded AIS (Automatic Identification System) message, sent by a transmitter (310;400;610) in the form of a first signal which is a modulated radio signal (520), which receiving device comprises an antenna (501) arranged to receive the first signal giving rise to a second signal in the form of an analogue electrical signal, an AD converter (503), which AD converter is arranged to sample the said analogue signal, which sampling can be performed in any order in relation to any demodulation of the second signal, resulting in a digitally stored third signal in the form of a sampled signal, which receiving device furthermore comprises a decoding device (504), arranged to decode the third signal and thereby to achieve the data content of the message as a stream of data bits, which stream of data bits comprises a predetermined signal element whose time of receipt is determined, and wherein the receiving device is arranged to determine the time of receipt of the message based on the timing of the predetermined signal element, and whereby the receiving device comprises a time determination device (508), arranged to determine the time of receipt of the predetermined signal element, **characterised in that** the timing determination device is arranged to construct a digital comparison signal on the basis of said stream of data bits, so that the constructed comparison signal is constructed to simulate the third signal, **in that** the timing determination device is arranged to determine an optimum value for a time variable, which time variable indicates a time position of the constructed comparison signal relative to the third signal and for which optimum value a correlation between the constructed comparison signal and the third signal is maximal, and **in that** the timing determination device is arranged to correct the said timing determination of the predetermined signal element

using the optimum value of the time variable.

12. System for determining the location for a sender (310;400) emitting a binary coded AIS (Automatic Identification System) message in the form of a modulated radio signal (520), **characterised in that** the system comprises at least three receiving devices (320,330,340) according to claim 11, each one comprising a respective clock (507), which clocks are synchronized, and which receiving devices are arranged to receive one and the same radio signal (520) from the sender, **in that** each one of the receiving devices is arranged to determine the time of receipt of the same predetermined signal element of the received signal, and **in that** the system is arranged to determine a location of the sender by triangulation based upon the respective location of the three receivers in combination with differences in the respective point in time for the receipt of the said signal element.

## Patentansprüche

1. Verfahren zum Bestimmen der Empfangszeit einer binär codierten AIS-Nachricht (Automatic Identification System) durch einen Funkempfänger (320, 330, 340; 500; 620), die von einem Sender (310; 400; 610) in Form eines ersten Signals gesendet wird, das ein moduliertes Funksignal (520) ist, wobei das erste Signal vom Empfänger unter Verwendung einer Antenne (501) empfangen wird, was zu einem zweiten Signal in Form eines analogen elektrischen Signals führt, welches zweite Signal abgetastet wird, welches Abtasten in einer beliebigen Reihenfolge in Bezug auf eine beliebige Demodulation des zweiten Signals durchgeführt werden kann, welches Abtasten unter Verwendung eines AD-Wandlers (503) durchgeführt wird, was zu einem digital gespeicherten dritten Signal in Form eines abgetasteten Signals führt, wobei der Dateninhalt der Nachricht vom dritten Signal als ein Strom von Datenbits bestimmt wird, welcher Strom von Datenbits ein vorbestimmtes Signalelement enthält, dessen Empfangszeit bestimmt wird, und wobei die Empfangszeit der Nachricht basierend auf der Taktung des vorbestimmten Signalelements bestimmt wird, **dadurch gekennzeichnet, dass** ein digitales Vergleichssignal auf der Basis des Stroms von Datenbits so konstruiert wird, dass das konstruierte Vergleichssignal konstruiert ist, um das dritte Signal zu simulieren, dass ein optimaler Wert für eine Zeitvariable bestimmt wird, welche Zeitvariable eine Zeitposition des konstruierten Vergleichssignals bezüglich des dritten Signals anzeigt und für welchen optimalen Wert eine Korrelation zwischen dem konstruierten Vergleichssignal und dem dritten Signal maximal ist, und dass der optimale Wert der Zeitva-

riablen verwendet wird, um die Bestimmung der Empfangszeit des vorbestimmten Signalelements zu korrigieren.

2. Verfahren nach Anspruch 1, **dadurch gekennzeichnet, dass** das dritte Signal durch analoge Modulation des zweiten Signals gefolgt von einer Abtastung des resultierenden entsprechend modulierten Signals erhalten wird.

3. Verfahren nach Anspruch 1 oder 2, **dadurch gekennzeichnet, dass** das erste Signal vor der Modulation durch den Sender (310; 400; 610) unter Verwendung eines bestimmten Filters gefiltert wird, und dass das Vergleichssignal durch entsprechendes Filtern eines digitalen Signals, das den Dateninhalt darstellt, unter Verwendung eines Filters mit im Wesentlichen den gleichen Eigenschaften wie das bestimmte Filter konstruiert wird.

4. Verfahren nach Anspruch 1 oder 2, **dadurch gekennzeichnet, dass** das konstruierte Vergleichssignal vor der Berechnung der Korrelationen unter Verwendung eines Filters gefiltert wird, so dass Abweichungen des dritten Signals, die als Konsequenz der analogen Frequenz- und/oder Phasenantwort des Empfängers (320, 330, 340; 500; 620) auftreten, vor der Abtastung unter Verwendung des Filters simuliert werden.

5. Verfahren nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** der AD-Wandler (503) mindestens ein Unterbrechungssignal sendet, um einen bestimmten Abtastzeitpunkt zu markieren, dass die Sendezeit eines solchen Unterbrechungssignals unter Verwendung eines Taktgebers (507) im Empfänger bestimmt wird, und dass die Zeitbestimmung des Empfangs des vorbestimmten Signalelements auf dem getakteten Senden des Unterbrechungssignals durch Beziehen des Sendens des Unterbrechungssignals auf eine bestimmte Zeitposition des dritten Signals basiert.

6. Verfahren nach Anspruch 5, **dadurch gekennzeichnet, dass** der AD-Wandler (503) eine Anzahl von Unterbrechungssignalen in vorbestimmten Zeitintervallen sendet, wobei der Zeitpunkt des Sendens mehrerer solcher jeweiliger Unterbrechungssignale unter Verwendung des Taktgebers (507) bestimmt wird, und die unter Verwendung des Zeitintervalls angepasst werden, um den Zeitpunkt des Sendens eines bestimmten Unterbrechungssignals zu schätzen, dass diese angepassten Taktbestimmungen so gemittelt werden, dass eine gemittelte Taktbestimmung des Sendens des bestimmten Unterbrechungssignals erhalten wird, dass die Taktbestimmung des Empfangs des vorbestimmten Signalelements auf der gemittelten Taktbestimmung des

Sendens des bestimmten Unterbrechungssignals durch Beziehen des bestimmten Unterbrechungssignals auf eine bestimmte Zeitposition des abgetasteten Signals basiert.

7. Verfahren nach Anspruch 5 oder 6, **dadurch gekennzeichnet, dass** der Taktgeber (507) einen lokalen Oszillator aufweist, der regelmäßig mit der Zeitinformation in einem empfangenen GPS-Signal (Global Positioning System) (530) synchronisiert wird.

8. Verfahren nach einem der vorhergehenden Ansprüche, **dadurch gekennzeichnet, dass** der Standort des Senders (310; 400; 610) dem Empfänger (320, 330, 340; 500; 620) bekannt ist, und dass ein gemeinsamer Zeitpunkt zwischen dem Sender und dem Empfänger dadurch synchronisiert wird, dass der Empfänger die Taktbestimmung des Empfangs des vorbestimmten Signalelements für die Zeit korrigiert, die das Funksignal (520) braucht, um sich zwischen dem Sender und dem Empfänger zu bewegen, basierend auf der Entfernung zwischen den Standorten des Senders und des Empfängers.

9. Verfahren nach Anspruch 7, **dadurch gekennzeichnet, dass** mindestens drei Empfänger (320, 330, 340), deren Taktgeber (507) vorher synchronisiert wurden, das gleiche Funksignal (520) von einem bestimmten Sender (310) empfangen, dass jeder der Empfänger die Taktung des Empfangs des gleichen vorbestimmten Signalelements des empfangenen Signals bestimmt, und dass ein Standort des Senders durch Triangulation von einer Zentraleinheit (350) in Kommunikation mit den mindestens drei Empfängern bestimmt wird, basierend auf dem jeweiligen Standort der drei Empfänger in Kombination mit Unterschieden der Zeitpunkte für den Empfang des Signalelements.

10. Verfahren nach Anspruch 9, **dadurch gekennzeichnet, dass** der berechnete Standort für den Sender (310; 400; 610), und/oder ein Kurs und/oder eine Geschwindigkeit, die basierend auf mehreren aufeinanderfolgenden Berechnungen des Standorts des Senders berechnet wurden, mit einem Standort und/oder einem Kurs und/oder einer Geschwindigkeit für den Sender verglichen werden, die in einer AIS-Nachricht (Automatic Identification System) angegeben wird, die vom Sender gesendet wird, und dass ein Warnsignal gesendet wird, wenn die zwei Positionen und/oder Kurse und/oder Geschwindigkeiten sich paarweise um mehr als ein vorbestimmter Wert unterscheiden.

11. Empfangsvorrichtung (320, 330, 340; 500; 620), die eingerichtet ist, um eine binär codierte AIS-Nachricht (Automatic Identification System) zu empfangen, die von einem Sender (310; 400; 610) in Form eines ersten Signals gesendet wird, das ein moduliertes Funksignal (520) ist, welche Empfangsvorrichtung eine Antenne (501), die eingerichtet ist, um das erste Signal zu empfangen, das zu einem zweiten Signal in Form eines analogen elektrischen Signals führt, und einen AD-Wandler (503) aufweist, welcher AD-Wandler eingerichtet ist, um das analoge Signal abzutasten, welches Abtasten in einer beliebigen Reihenfolge in Bezug auf eine beliebige Demodulation des zweiten Signals durchgeführt werden kann, was zu einem digital gespeicherten dritten Signal in Form eines abgetasteten Signals führt, welche Empfangsvorrichtung weiter eine Decodiervorrichtung (504) aufweist, die eingerichtet ist, um das dritte Signal zu decodieren und dadurch den Dateninhalt der Nachricht als ein Strom von Datenbits zu erhalten, welcher Strom von Datenbits ein vorbestimmtes Signalelement aufweist, dessen Empfangszeit bestimmt wird, und wobei die Empfangsvorrichtung eingerichtet ist, um die Empfangszeit der Nachricht basierend auf der Taktung des vorbestimmten Signalelements zu bestimmen, und wobei die Empfangsvorrichtung eine Zeitbestimmungsvorrichtung (508) aufweist, die eingerichtet ist, um die Empfangszeit des vorbestimmten Signalelements zu bestimmen, **dadurch gekennzeichnet, dass** die Taktbestimmungsvorrichtung eingerichtet ist, um ein digitales Vergleichssignal auf der Basis des Stroms von Datenbits so zu konstruieren, dass das konstruierte Vergleichssignal konstruiert ist, um das dritte Signal zu simulieren, dass die Taktbestimmungsvorrichtung eingerichtet ist, um einen optimalen Wert für eine Zeitvariable zu bestimmen, welche Zeitvariable eine Zeitposition des konstruierten Vergleichssignals bezüglich des dritten Signals angibt und für welchen optimalen Wert eine Korrelation zwischen dem konstruierten Vergleichssignal und dem dritten Signal maximal ist, und dass die Taktbestimmungsvorrichtung eingerichtet ist, um die Taktbestimmung des vorbestimmten Signalelements unter Verwendung des optimalen Werts der Zeitvariablen zu korrigieren.

12. System zur Bestimmung des Standorts für einen Sender (310; 400), der eine binär codierte AIS-Nachricht (Automatic Identification System) in Form eines modulierten Funksignals (520) sendet, **dadurch gekennzeichnet, dass** das System mindestens drei Empfangsvorrichtungen (320, 330, 340) nach Anspruch 11 aufweist, die je einen Taktgeber (507) aufweisen, welche Taktgeber synchronisiert sind, und welche Empfangsvorrichtungen eingerichtet sind, um ein und dasselbe Funksignal (520) vom Sender zu empfangen, dass jede der Empfangsvorrichtungen eingerichtet ist, um die Empfangszeit des gleichen vorbestimmten Signalelements des empfangenen Signals zu bestimmen, und dass das System eingerichtet ist, um einen Standort des Senders

durch Triangulation basierend auf dem Standort der drei Empfänger in Kombination mit Unterschieden im jeweiligen Zeitpunkt für den Empfang des Signalelements zu bestimmen.

## Revendications

**1.** Procédé pour déterminer l'heure de réception par un récepteur radio (320, 330, 340 ; 500 ; 620) d'un message AIS (Système d'Identification Automatique) codé binaire, envoyé par un émetteur (310 ; 400 ; 610) sous la forme d'un premier signal qui est un signal radio modulé (520), moyennant quoi le premier signal est reçu par le récepteur en utilisant une antenne (501) donnant lieu à un deuxième signal sous la forme d'un signal électrique analogique, lequel deuxième signal est échantillonné, lequel échantillonnage peut être effectué dans n'importe quel ordre relativement à n'importe quelle démodulation du deuxième signal, lequel échantillonnage est effectué en utilisant un convertisseur AD (503), donnant lieu à un troisième signal stocké numériquement sous la forme d'un signal échantillonné, dans lequel le contenu de données du message est déterminé à partir du troisième signal comme un train de bits de données, lequel train de bits de données comprend un élément de signal prédéterminé dont l'heure de réception est déterminée, et dans lequel l'heure de réception du message est déterminée sur la base du positionnement temporel de l'élément de signal prédéterminé, **caractérisé en ce qu'**un signal de comparaison numérique est construit sur la base dudit train de bits de données, de sorte que le signal de comparaison construit soit construit pour simuler le troisième signal, **en ce qu'**une valeur optimale est déterminée pour une variable de temps, laquelle variable de temps indique une position temporelle du signal de comparaison construit par rapport au troisième signal et pour laquelle valeur optimale une corrélation entre le signal de comparaison construit et le troisième signal est maximale, et **en ce que** la valeur optimale de la variable de temps est utilisée pour corriger la détermination de l'heure de réception de l'élément de signal prédéterminé.

**2.** Procédé selon la revendication 1, **caractérisé en ce que** le troisième signal est obtenu par modulation analogique du deuxième signal, suivie de l'échantillonnage du signal modulé de manière correspondante résultant.

**3.** Procédé selon la revendication 1 ou 2, **caractérisé en ce que** le premier signal, avant la modulation par l'envoyeur (310 ; 400 ; 610), est filtré en utilisant un certain filtre, et **en ce que** le signal de comparaison est construit, de façon correspondante, en filtrant un signal numérique représentant ledit contenu de don-

nées en utilisant un filtre avec essentiellement les mêmes propriétés que ledit certain filtre.

**4.** Procédé selon la revendication 1 ou 2, **caractérisé en ce que** le signal de comparaison construit, avant le calcul desdites corrélations, est filtré en utilisant un filtre de sorte que des écarts du troisième signal, survenant en conséquence de la réponse en fréquence et/ou en phase analogique du récepteur (320, 330, 340 ; 500 ; 620) avant l'échantillonnage soient simulés en utilisant ledit filtre.

**5.** Procédé selon l'une quelconque des revendications précédentes, **caractérisé en ce que** le convertisseur AD (503) envoie au moins un signal d'interruption pour marquer un certain point temporel d'échantillonnage, **en ce que** l'heure d'émission d'un tel signal d'interruption est déterminée en utilisant une horloge (507) dans le récepteur, et **en ce que** la détermination de l'heure de la réception dudit élément de signal prédéterminé est basée sur l'envoi temporisé dudit signal d'interruption en liant l'envoi du signal d'interruption à une certaine position temporelle du troisième signal.

**6.** Procédé selon la revendication 5, **caractérisé en ce que** le convertisseur AD (503) envoie un nombre de signaux d'interruption à des intervalles de temps prédéterminés, dont l'heure d'envoi de plusieurs tels signaux d'interruption respectifs est déterminée en utilisant ladite horloge (507) et est ajustée en utilisant ledit intervalle de temps afin d'estimer le point dans le temps de l'envoi d'un certain signal d'interruption, **en ce que** ces déterminations de positionnement temporel ajustées sont moyennées de sorte qu'une détermination de positionnement temporel moyennée de l'envoi du certain signal d'interruption soit obtenue, **en ce que** la détermination de positionnement temporel de la réception dudit élément de signal prédéterminé est basée sur la détermination de positionnement temporel moyennée de l'envoi du certain signal d'interruption en liant le certain signal d'interruption à une certaine position temporelle du signal échantillonné.

**7.** Procédé selon la revendication 5 ou 6, **caractérisé en ce que** l'horloge (507) comprend un oscillateur local, qui est régulièrement synchronisé sur les informations temporelles dans un signal GPS (Système Mondial de Positionnement) reçu (530).

**8.** Procédé selon l'une quelconque des revendications précédentes, **caractérisé en ce que** la localisation de l'envoyeur (310 ; 400 ; 610) est connue du récepteur (320, 330, 340 ; 500 ; 620), et **en ce qu'**un point commun dans le temps est synchronisé entre l'envoyeur et le récepteur par le récepteur corrigeant la détermination de positionnement temporel de la ré-

ception dudit élément de signal prédéterminé pendant le temps que cela prend pour que le signal radio (520) se déplace entre l'envoyeur et le récepteur, sur la base de la distance entre les localisations de l'envoyeur et du récepteur, respectivement.

9. Procédé selon la revendication 7, **caractérisé en ce qu'**au moins trois récepteurs (320, 330, 340), dont les horloges respectives (507) ont été préalablement synchronisées, reçoivent un seul et même signal radio (520) d'un certain envoyeur (310), **en ce que** chacun des récepteurs détermine le positionnement temporel de la réception du même élément de signal prédéterminé du signal reçu, et **en ce qu'**une localisation de l'envoyeur est déterminée par triangulation, par une unité centrale (350) en communication avec lesdits au moins trois récepteurs, sur la base de la localisation respective des trois récepteurs en combinaison avec des différences dans le point dans le temps respectif pour la réception respective dudit élément de signal.

10. Procédé selon la revendication 9, **caractérisé en ce que** la localisation calculée pour l'envoyeur (310 ; 400 ; 610), et/ou un cap et/ou une vitesse qui a été calculé sur la base de plusieurs calculs consécutifs de la localisation de l'envoyeur, est comparé à une localisation et/ou un cap et/ou une vitesse pour l'envoyeur qui est indiqué dans un message AIS (Système d'Identification Automatique) qui est envoyé depuis l'envoyeur, et **en ce qu'**un signal d'avertissement est émis dans le cas où les deux positions et/ou caps et/ou vitesses sont différents par paire de plus d'une valeur prédéterminée respective.

11. Dispositif de réception (320, 330, 340 ; 500 ; 620) agencé pour recevoir un message AIS (Système d'Identification Automatique) codé binaire, envoyé par un émetteur (310 ; 400 ; 610) sous la forme d'un premier signal qui est un signal radio modulé (520), lequel dispositif de réception comprend une antenne (501) agencée pour recevoir le premier signal engendrant un deuxième signal sous la forme d'un signal électrique analogique, un convertisseur AD (503), lequel convertisseur AD est agencé pour échantillonner ledit signal analogique, lequel échantillonnage peut être effectué dans n'importe quel ordre relativement à n'importe quelle démodulation du deuxième signal, donnant lieu à un troisième signal stocké numériquement sous la forme d'un signal échantillonné, lequel dispositif de réception comprend en outre un dispositif de décodage (504), agencé pour décoder le troisième signal et réaliser ainsi le contenu de données du message comme un train de bits de données, lequel train de bits de données comprend un élément de signal prédéterminé dont l'heure de réception est déterminée, et dans lequel le dispositif de réception est agencé pour dé-

terminer l'heure de réception du message sur la base du positionnement temporel de l'élément de signal prédéterminé, et moyennant quoi le dispositif de réception comprend un dispositif de détermination de temps (508), agencé pour déterminer l'heure de réception de l'élément de signal prédéterminé, **caractérisé en ce que** le dispositif de détermination de positionnement temporel est agencé pour construire un signal de comparaison numérique sur la base dudit train de bits de données, de sorte que le signal de comparaison construit soit construit pour simuler le troisième signal, **en ce que** le dispositif de détermination de positionnement temporel est agencé pour déterminer une valeur optimale pour une variable de temps, laquelle variable de temps indique une position temporelle du signal de comparaison construit par rapport au troisième signal et pour laquelle valeur optimale une corrélation entre le signal de comparaison construit et le troisième signal est maximale, et **en ce que** le dispositif de détermination de positionnement temporel est agencé pour corriger ladite détermination de positionnement temporel de l'élément de signal prédéterminé en utilisant la valeur optimale de la variable de temps.

12. Système pour déterminer la localisation pour un envoyeur (310 ; 400) émettant un message AIS (Système d'Identification Automatique) codé binaire sous la forme d'un signal radio modulé (520), **caractérisé en ce que** le système comprend au moins trois dispositifs de réception (320, 330, 340) selon la revendication 11, chacun comprenant une horloge respective (507), lesquelles horloges sont synchronisées, et lesquels dispositifs de réception sont agencés pour recevoir un seul et même signal radio (520) de l'envoyeur, **en ce que** chacun des dispositifs de réception est agencé pour déterminer l'heure de réception du même élément de signal prédéterminé du signal reçu, et **en ce que** le système est agencé pour déterminer une localisation de l'envoyeur par triangulation sur la base de la localisation respective des trois récepteurs en combinaison avec des différences dans le point dans le temps respectif pour la réception dudit élément de signal.
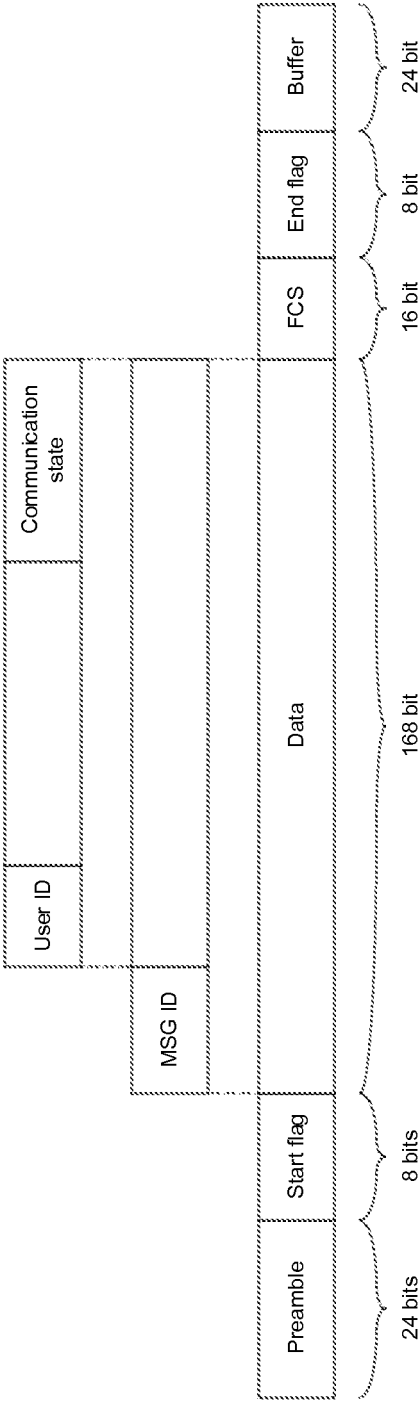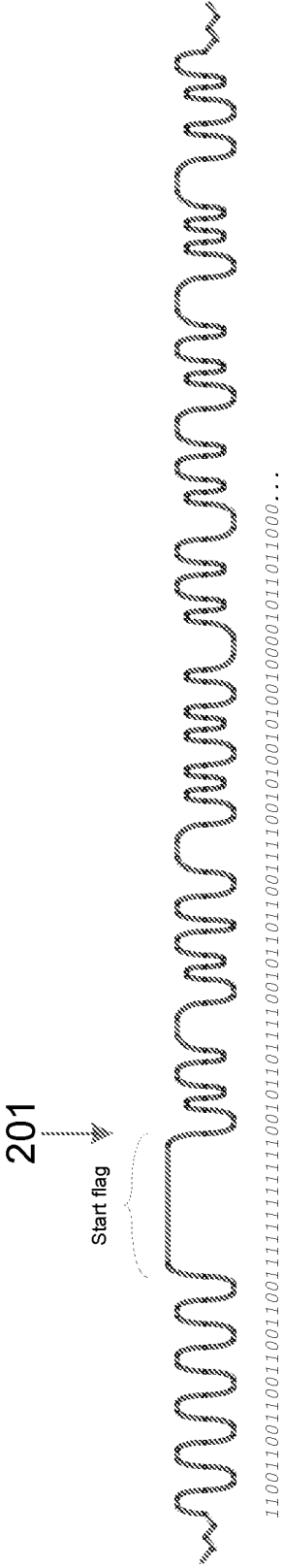
**Fig. 1**

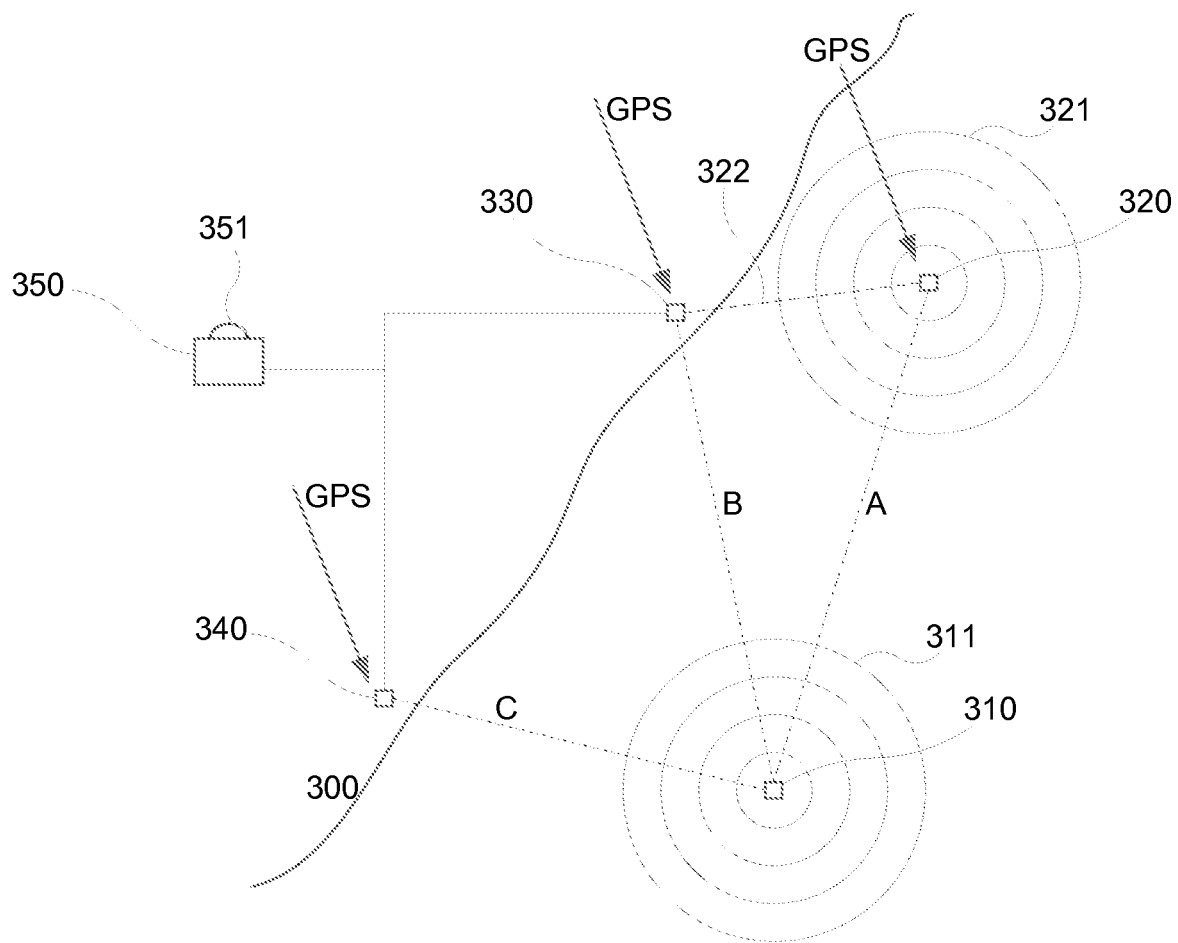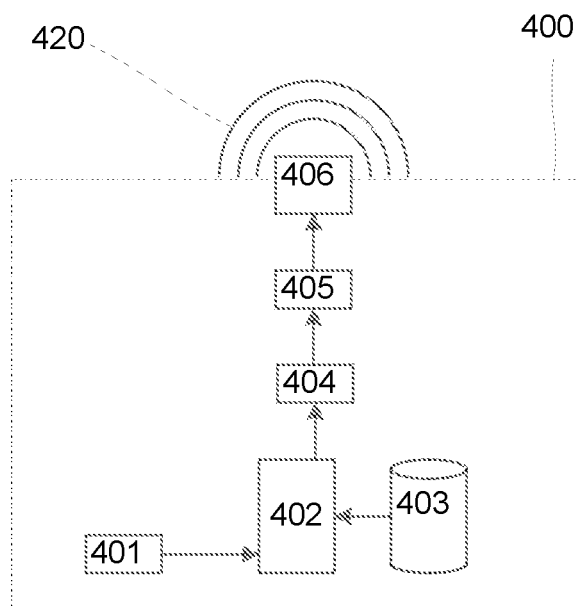| Preamble | Start flag | | | | | FCS | End flag | Buffer |
|---|---|---|---|---|---|---|---|---|
| | | User ID | Communication state | | | | | |
| | | MSG ID | | Data | | | | |

| 24 bits | 8 bits | | | 168 bit | | 16 bit | 8 bit | 24 bit |

**Fig. 2**

201

Start flag

1100110011001100111111111110010101110011001001000010101101000...

# Fig. 3



# Fig. 4

Fig. 5b



Fig. 5a

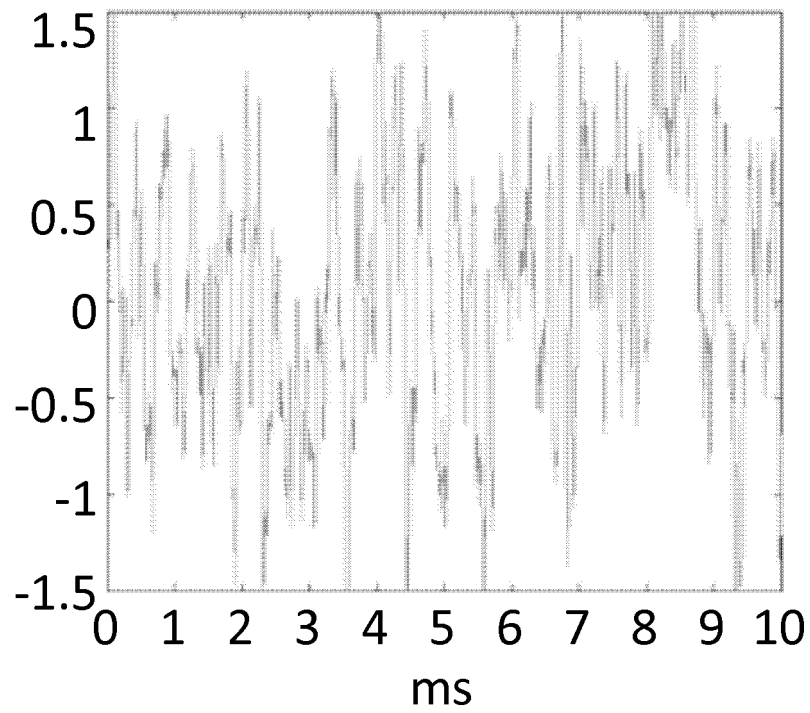**Fig. 6**

## Fig. 7a
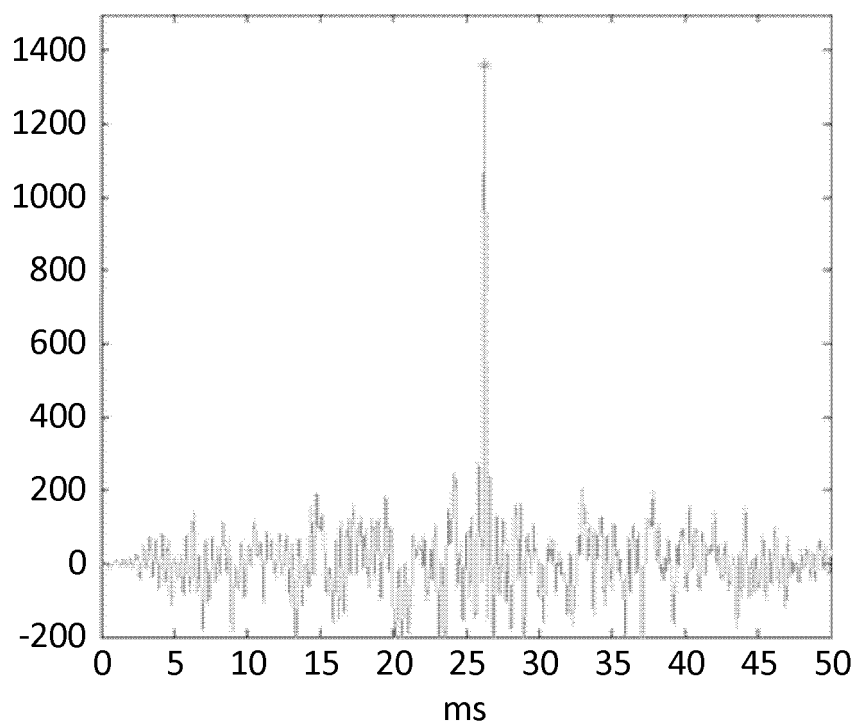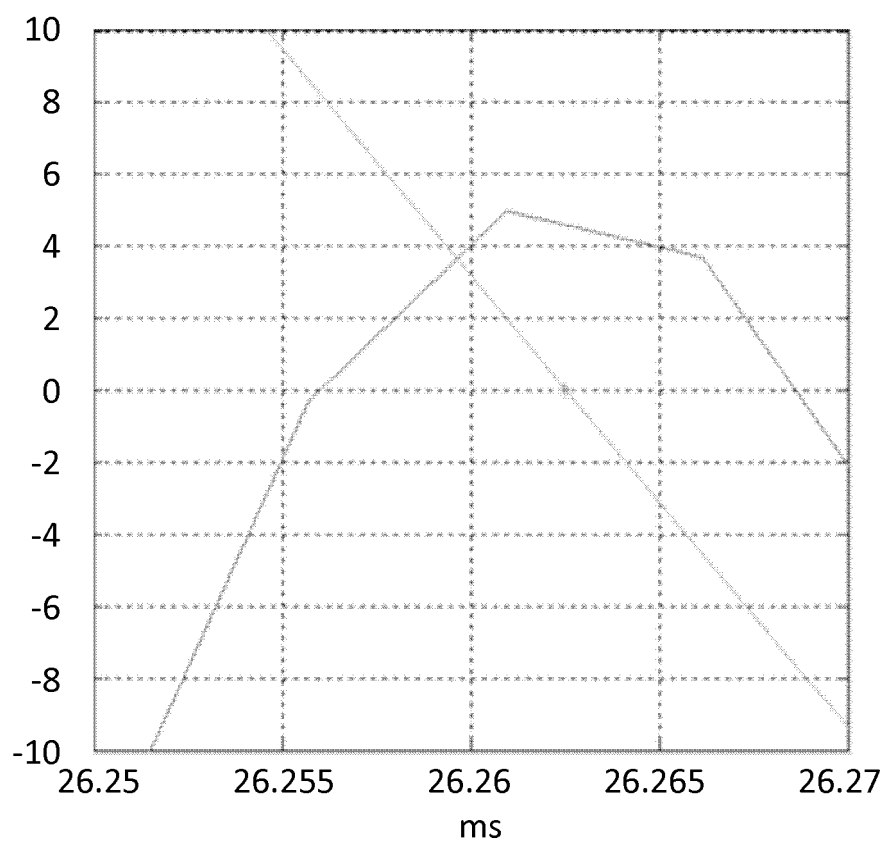


ms

## Fig. 7b



ms
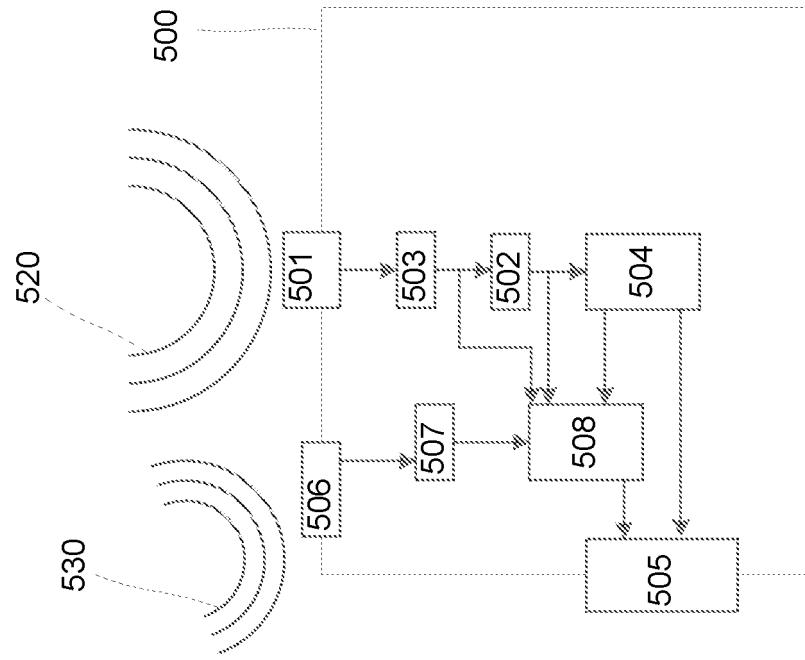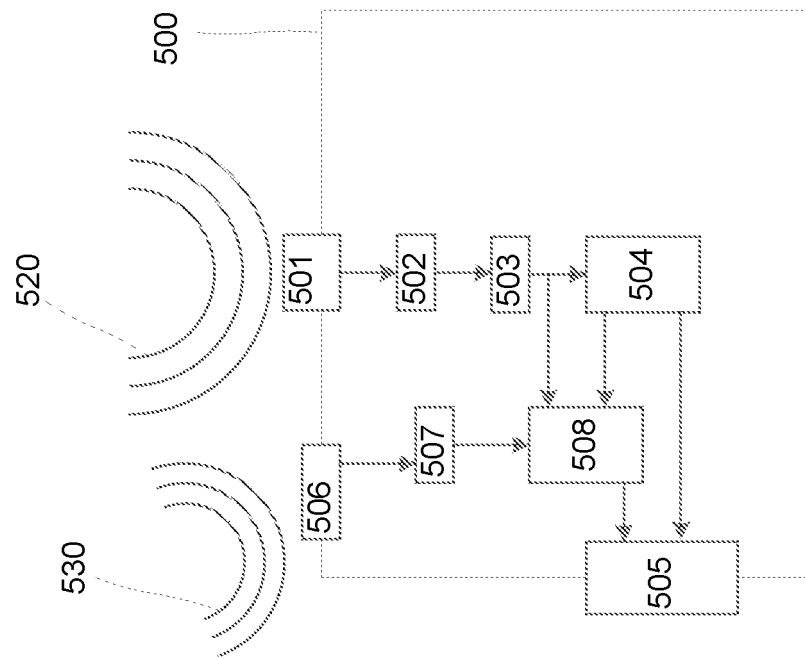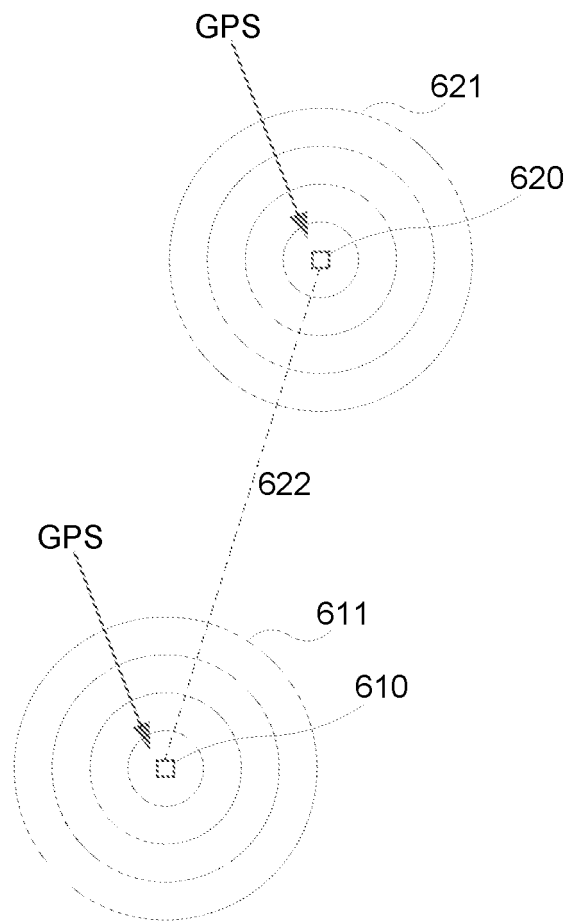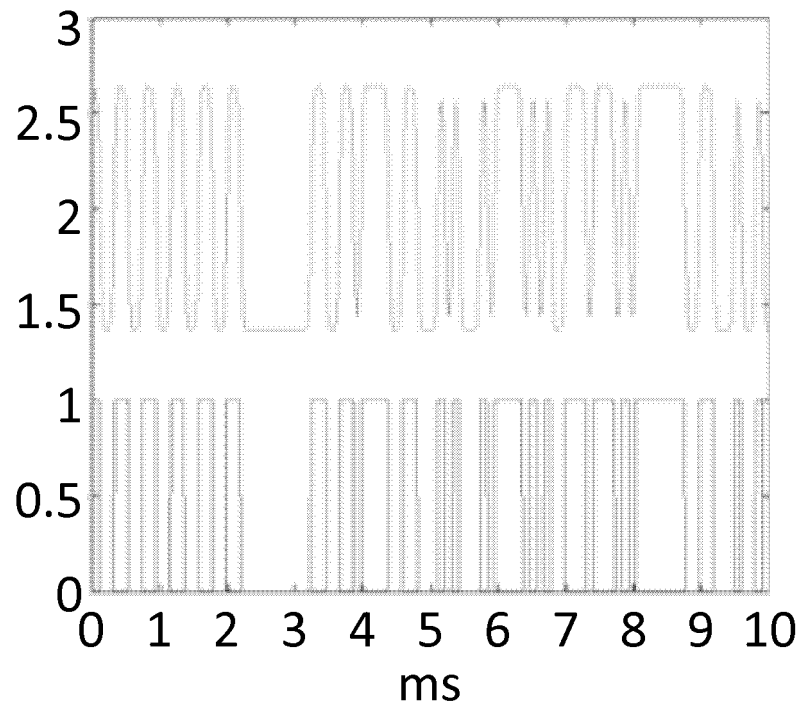
# Fig. 7c



# Fig. 7d

## REFERENCES CITED IN THE DESCRIPTION

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**Patent documents cited in the description**

- US 20070276616 A1 **[0010]**

**Non-patent literature cited in the description**

- Recommendation ITU-R M.1371-4. International Telecommunication Union, 2010 **[0002]**