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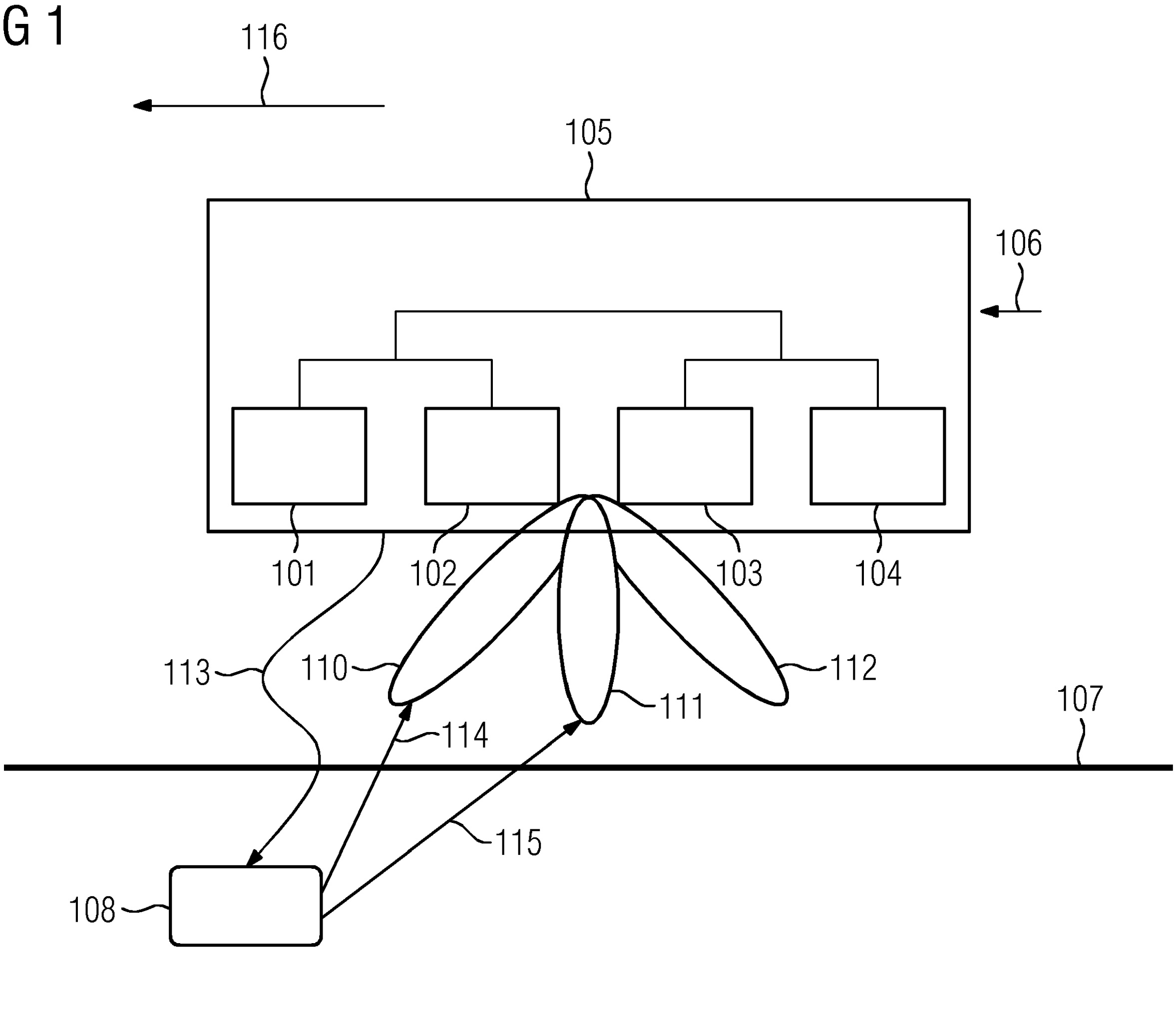
(54) **ON-BOARD ANTENNA FOR RAIL VEHICLE**

(57) An on-board antenna for a rail vehicle is provided, comprising several antenna elements that are arranged and configured to form at least two beams, wherein the at least two beams are directed at different angles towards a track. In addition, a rail vehicle is provided utilizing such on-board antenna for obtaining signals from a balise. Also, a method is provided to monitor the rail vehicle via such on-board antenna.

FIG 1



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Description

[0001] The invention relates to an on-board antenna and to a method operating this on-board antenna. The on-board antenna is part of a rail vehicle and may in particular interact with a balise.

[0002] A balise is known to be an electronic beacon or transponder placed between the rails of a railway as part of an automatic train protection (ATP) system (see, e.g., en.wikipedia.org/wiki/Balise). Balises constitute an integral part of the European Train Control System (ETCS), where they serve as "beacons" giving the exact location of a train. For further details regarding ETCS, reference is made to, e.g., en.wikipedia.org/wiki/European_Train_Control_System.

[0003] In a known and common use-case scenario, an on-board antenna for a rail vehicle has a telepowering loop to activate a balise and another receiver loop for receiving the uplink signal supplied by the balise. The on-board antenna has an omnidirectional pattern and receives signals from various angles.

[0004] A detection of a balise is currently subject to some uncertainty with regard to the actual position of the balise. However, a detection of a balise position at a high accuracy is a general motivation to enable applications like supervision of platform screen doors or station stopping of a rail vehicle.

[0005] In addition, cross-talk has a strong impact on detecting the position of a balise. Such cross-talk may stem from signals that are radiated from other balises of the same track and/or from balises of neighboring tracks. For example, telepowering may activate balises on the same track or on adjacent tracks. These activated balises emit signals that may interfere with the signal that should be detected by the rail vehicle. These unwanted signals are referred to as cross-talk. Based on cross-talk, the rail vehicle may determine a wrong position, because it receives a signal from a wrong balise (i.e. a balise that is not being passed over by the rail vehicle).

[0006] It is also a disadvantage, that the information provided by a balise to the rail vehicle does not suffice to determine a direction of travel. In fact, the rail vehicle needs to pass multiple balises on the same track in order to determine its direction.

[0007] The **objective** is thus to overcome the disadvantages stated above and in particular to provide a solution that allows improving an on-board detection system of a rail vehicle for detecting balises.

[0008] This problem is solved according to the features of the independent claims. Further embodiments result from the depending claims.

[0009] In order to overcome this problem, an on-board antenna for a rail vehicle is suggested, comprising

- several antenna elements that are arranged and configured to form at least two beams,
- wherein the at least two beams are directed at different angles towards a track.

[0010] In this regard, the on-board antenna may comprise a control unit to feed the antenna to enable beamforming. The at least two beams are directed towards a rail track, in particular towards balises that are located at, in or adjacent to the track. The at least two beams point towards the track at a different angle. That allows detecting a signal (information) from a balise at a different time for each of the at least two beams.

[0011] It is noted that the angles may vary between +45° and -45° with a minimum separation amounting to, e.g., 25° between any two beams.

[0012] In an embodiment, at least two of the antenna elements are arranged in doublets.

[0013] In an embodiment, the at least two beams comprise

- a first beam which is directed at an angle of Φ towards the track, and
- a second beam which is directed at an angle of $-\Phi$ towards the track,
- wherein the angle Φ is in the range from 30° to 80°.

[0014] In an embodiment, the at least two beams comprise a third beam, which is directed at an angle of 90° towards the track.

[0015] Further, a rail vehicle is provided comprising a processing unit that is arranged to control the on-board antenna as described herein. The at least two beams comprise a first beam and a second beam. The processing unit is arranged

- to receive an information from a balise via the first beam at a first time,
- to receive the information from the balise via the second beam at a second time,
- to determine the position of the rail vehicle based on the first information and on the second information.

[0016] Due to the succession of receptions of the information of the balise within a given time frame, the position of the balise can be verified and thus the position of the rail vehicle can be determined based on the verified position of the balise.

[0017] It is in particular noted that the second time is later than the first time.

[0018] Hence, the train (rail vehicle) receives the ID of the balise several times in short succession (within a time frame) and hence knows that it is crossing the balise. This allows verifying this particular balise by the ID (because of the several receptions of the ID by the several beams) and it allows determining the position of the train, because the train is (was) at the position of this particular balise, which is globally known (e.g., it is known that the balise ID is mounted at the coordinates xy in the track). The information supplied by the balise may in particular comprise the position of the balise or a database that is accessible to the train supplies the location of the respective balise.

[0019] Hence, the solution presented allows to efficiently determine the position of the rail vehicle, e.g., train. Also, the direction of movement of the rail vehicle can be determined.

[0020] In an embodiment, the processing unit is arranged to determine the presence of the balise based on the information provided at the first time via the first beam and the information provided at the second time via the second beam.

[0021] In an embodiment, the processing unit is arranged to determine a direction of movement of the rail vehicle based on the succession of the information provided at the first time via the first beam and the information provided at the second time via the second beam.

[0022] In an embodiment, the processing unit is arranged to determine and cancel cross-talk based on the succession of the information provided at the first time via the first beam and the information provided at the second time via the second beam.

[0023] In an embodiment, the processing unit is arranged to determine a velocity of the rail vehicle based on the information provided at the first time via the first beam and the information provided at the second time via the second beam.

[0024] Further, a method is suggested for monitoring a rail vehicle comprising a processing unit that is arranged to control the on-board antenna as described herein, wherein the at least two beams comprise a first beam and a second beam, the method comprising:

- receiving an information from a balise via the first beam at a first time,
- receiving the information from the balise via the second beam at a second time,
- determining the position of the rail vehicle based on the first information and on the second information.

[0025] In an embodiment, the method further comprises

- determining the presence of the balise based on the information provided at the first time via the first beam and the information provided at the second time via the second beam.

[0026] In an embodiment, the method further comprises

- determining a direction of movement of the rail vehicle based on the succession of the information provided at the first time via the first beam and the information provided at the second time via the second beam.

[0027] In an embodiment, the method further comprises

- determining and canceling cross-talk based on the succession of the information provided at the first time via the first beam and the information provided at the second time via the second beam.

[0028] In an embodiment, the method further comprises

- determining a velocity of the rail vehicle based on the information provided at the first time via the first beam and the information provided at the second time via the second beam.

[0029] It is noted that the steps of the method stated herein may be executable on this processing unit as well.

[0030] It is further noted that said processing unit can comprise at least one, in particular several means that are arranged to execute the steps of the method described herein. The means may be logically or physically separated; in particular several logically separate means could be combined in at least one physical unit.

[0031] Said processing unit may comprise at least one of the following: a processor, a microcontroller, a hard-wired circuit, an ASIC, an FPGA, a logic device.

[0032] The solution provided herein further comprises a computer program product directly loadable into a memory of a digital computer, comprising software code portions for performing the steps of the method as described herein.

[0033] In addition, the problem stated above is solved by a computer-readable medium, e.g., storage of any kind, having computer-executable instructions adapted to cause a computer system to perform the method as described herein.

[0034] The aforementioned characteristics, features and advantages of the invention as well as the way they are achieved will be further illustrated in connection with the following examples and considerations as discussed in view of the figures.

Fig.1 visualizes how beam forming is utilized via several antenna elements of an on-board antenna of a rail vehicle;

Fig.2 shows an arrangement similar to Fig.1 with a second balise that contributes to cross-talk;

Fig.3 shows an exemplary on-board antenna arrangement comprising several antenna elements to form various beams.

[0035] Examples described herein are in particular directed to an antenna array (e.g., doublets) that allow forming a beam pattern with specific angles. These beam patterns can be used to find the direction of arrival of received signals. This can be done by a solution described in [Rias Muhamed: "Direction of Arrival Estimation using Antenna Arrays", Thesis submitted to the Faculty of the Virginia Polytechnic Institute and State University, January 1996, available at https://theses.lib.vt.edu/theses/available/etd-10022008-063154/unrestricted/LD5655.V855_1996.M843.pdf)], which is hereinafter referred to as [1]. Hence, the balise can be detected with an increased accuracy. Also, cross-talk of other balises can be identified and ignored.

[0036] Fig.1 visualizes how beam forming is utilized via several antenna elements 101 to 104 of an on-board antenna 105 of a rail vehicle. The antenna elements 101 to 104 may be individually controlled (as is indicated by an arrow 106).

[0037] The rail vehicle moves in a direction 116.

[0038] Hence, the antenna elements 101 to 104 can be used to provide beams 110, 111 and 112 of different directions. In this example, the beam 110 has an angle of 45°, the beam 111 has an angle of 90° and the beam 112 has an angle of -45° with regard to the direction of a track 107.

[0039] Fig.1 also shows the track 107 and a balise 108 that is located adjacent to the track 107.

[0040] A telepowering signal 113 that is sent from the rail vehicle towards the balise 108 activates the balise 108. Subsequent to such activation, the balise 108 sends an information (comprising, e.g., an identification of the balise 108) as is indicated by arrows 114 and 115.

[0041] At a time T0, the rail vehicle receives the information from the balise 108 via the beam 110, which has a direction of arrival amounting to ca. 45°.

[0042] At a later time T0+x, the rail vehicle receives the information from the balise 108 via the beam 111, which has a direction of arrival amounting to ca. 90°.

[0043] At a subsequent time T0+nx, the rail vehicle receives the information from the balise 108 via the beam 112, which has a direction of arrival amounting to ca. -45°.

[0044] Hence, there is an increase (in particular change according to the angles of the beams 110 to 112) of the direction of arrival (DOA) of the received signals with an increasing time.

[0045] The direction 116 can be determined after the train has passed over the a single balise 108.

[0046] The information of the balise 108 are thus received via the three beams 110, 111 and 112 at different moments in times, i.e. with timestamps that show an increase of time.

[0047] Additional signals that may be received via multipath scattering can be filtered out, which allows validating the balise 108.

[0048] Also, if the approximated separation (at the balise 108) between the beams 110 and 112 is known, a velocity of the rail vehicle can be approximated based on the timestamps of the information received via the beams 110 and 112. An estimated calculation may be as follows: A distance between the beam 110 and the beam 112 may amount to d and it may preferably be a constant distance. The uplink signal from the balise 108 is received at the beam 110 at a time T0 and at the beam 112 at a time T1. Hence, a velocity may amount to approximately d/ (T1-T0).

[0049] Fig.2 shows an arrangement that is similar to Fig.1. However, in Fig.2 a second balise 109 is present, which supplies an information M2 (comprising an identification of the balise 109), which in this example corresponds to (unwanted) cross-talk 201 when the rail vehicle passes the balise 108.

[0050] The information supplied by the balise 108 is hereinafter referred to as information M1.

[0051] At a time T0, the rail vehicle receives the information M1 from the balise 108 via the beam 110, which has a direction of arrival amounting to ca. 45°. Also, at the time T0, the rail vehicle receives the information M2 from the balise 109 via the beam 112, which has a direction of arrival amounting to ca. -45°.

[0052] At a later time T0+x, the rail vehicle receives the information M1 from the balise 108 via the beam 111, which has a direction of arrival amounting to ca. 90°. Also, at the time T0+x, the rail vehicle receives the information M2 from the balise 109 via the beam 112, which has a direction of arrival amounting to ca. -45°.

[0053] At a subsequent time T0+nx, the rail vehicle receives the information M1 from the balise 108 and the information M2 from the balise 109 via the beam 112, which has a direction of arrival amounting to ca. -45°.

[0054] Hence, the antenna 105 of the rail vehicle at any moment of this example receives the information M1 and the information M2 from both balises 108 and 109. Due to the angles of the beams 110, 111, 112, the antenna 105 will receive the information M1 and the information M2 via different beams 110 to 112 (and hence different angles) with considerable phase shift.

[0055] A direction of arrival (DOA) algorithm is provided in [1]. The algorithm referred to is shown on page 114 of [1]. At the end of the algorithm, the balise 108 may be confirmed, cross-talk from the wrong balise 109 can be discarded.

[0056] The balise 108 can be validated if the information M1 is subsequently received at the beams 110, 111 and 112.

[0057] Hence, cross-talk that only is received by beam 112 can be identified and discarded. The same applies to cross-talk that is only received by beam 111 and beam 112. In the example of Fig.2, cross-talk (i.e. the information M2 from the balise 109) is present only at the DOA of beam 112, which can accordingly be identified and discarded. However, the information M1 from the balise 108 being successively received at the DOAs of beams 110, 111 and 112 allows validating the balise 108.

[0058] Also, the timestamps at which the information M1 is received at each at these DOAs utilized for various applications. Reference is also made to the algorithm described in [1].

[0059] Fig.3 shows an exemplary on-board antenna arrangement comprising several antenna elements 301 to 306 to supply the beams 110, 111 and 112. The antenna elements 301 to 306 are arranged in doublets, wherein the doublet comprising the antenna elements

301, 302 is arranged substantially perpendicular to the doublet comprising the antenna elements 303, 304. The doublet comprising the antenna elements 305, 306 is arranged substantially perpendicular in parallel to the doublet comprising the antenna elements 301, 302.

[0060] The antenna element 301 and the antenna element 302 are fed via a phase shifter 307, which is connected to a power divider and impedance network 309.

[0061] The antenna element 303 and the antenna element 304 are connected to the power divider and impedance network 309.

[0062] The antenna element 305 and the antenna element 306 are fed via a phase shifter 308, which is connected to the power divider and impedance network 309.

[0063] The power divider and impedance network 309 is supplied by a power source 310. The phase shifter 307 may introduce a phase shift amounting to Φ and the phase shifter 308 may introduce a phase shift amounting to -Φ. A range (for generated beams) may preferably be less than 77.5 degrees and larger than 45 degrees with reference to the track.

[0064] The separation 311, 312, 313 between the antenna elements may be any fractional value of $\lambda/2$, wherein λ is the transmission wavelength. Advantageously, the separation 311, 312, 313 may be arranged such that the beams 110 to 112 have a half power beam width separation of a fractional value of lambda ($x\lambda$). This may add to the flexibility in receiving the information from the balise at different DOA angles at different timestamps.

Advantages and further embodiments

[0065] Hence, the examples described herein may in particular suggest providing a multi-beam system with adaptive beams and low side lobe levels as on-board antenna of a rail vehicle. The antenna elements may be supplied, e.g., as single antennas or in doublet antennas. The doublet antennas may in particular be separated by identical distances.

[0066] An adaptive beam-forming as described in [1] may be applied to form multiple beams at different angles in the elevation plane.

[0067] Based on each of the multiple beams, a direction (or angle) of arrival (as described in [1]) of received signals may be determined at the on-board antenna of the rail vehicle. For this purpose, the rail vehicle comprises a receiver with said on-board antenna. The received signal may be transmitted from a transponder, e.g., a balise that is located within or adjacent to the track. Hence, when passing the balise, the balise may send an information (comprising, e.g., an identification of the balise) towards the rail vehicle, which is then received at the differently angled beams of the on-board antenna at different times.

[0068] The solution presented herein allows determining a direction of movement of the rail vehicle based on the information received at any two of the beams: The beam that receives the information first indicates the direction of movement. This may work in case at least two beams are used. As an option, synchronized clocks may be used.

[0069] Also, the location of the balise can be determined and in particular validated with high accuracy by the information received at the beams.

[0070] Further, cross-talk or any unwanted interference (e.g., signal reflections) can be detected and thus be discarded. In contrast to any disturbance, the information from the actual balise to be detected follows a pattern that is to be detected via the several beams (in the example shown in Fig.2, the information from the balise 108 is detected first by the beam 110, then by the beam 111 and subsequently by the beam 112).

[0071] In addition, a velocity of the rail vehicle can be determined based on the information received via the several beams, in particular via beams that have an opposing phase difference (in the example shown in Fig.1, by the beams 110 and 112).

[0072] The solution presented increases the flexibility in installing balises, because the on-board antenna is able to determine and cancel cross-talk from various balises and it increases the detection accuracy of balises.

[0073] Although the invention is described in detail by the embodiments above, it is noted that the invention is not at all limited to such embodiments. In particular, alternatives can be derived by a person skilled in the art from the exemplary embodiments and the illustrations without exceeding the scope of this invention.

Claims

1. On-board antenna (105) for a rail vehicle, comprising

- several antenna elements (101-104; 301-306) that are arranged and configured to form at least two beams (110-112),
- wherein the at least two beams are directed at different angles (45°, 90°, -45°) towards a track.

2. The on-board antenna according to claim 1, wherein at least two of the antenna elements are arranged in doublets.

3. The on-board antenna according to any of the preceding claims, wherein the at least two beams comprise

- a first beam which is directed at an angle of Φ towards the track, and
- a second beam which is directed at an angle of -Φ towards the track,
- wherein the angle Φ is in the range from 30° to 80°.

4. The on-board antenna according to claim 3, wherein the at least two beams comprise a third beam, which is directed at an angle of 90° towards the track.

5. A rail vehicle comprising a processing unit that is arranged to control the on-board antenna (105) according to any of the claims 1 to 4, wherein the at least two beams comprise a first beam (110) and a second beam (112), wherein the processing unit is arranged

- to receive an information from a balise (108) via the first beam at a first time,
- to receive the information from the balise (108) via the second beam at a second time,
- to determine the position of the rail vehicle based on the first information and on the second information.

6. The rail vehicle according to claim 5, wherein the processing unit is arranged to determine the presence of the balise based on the information provided at the first time via the first beam and the information provided at the second time via the second beam.

7. The rail vehicle according to any of claims 5 or 6, wherein the processing unit is arranged to determine a direction of movement of the rail vehicle based on the succession of the information provided at the first time via the first beam and the information provided at the second time via the second beam.

8. The rail vehicle according to any of claims 5 to 7, wherein the processing unit is arranged to determine and cancel cross-talk based on the succession of the information provided at the first time via the first beam and the information provided at the second time via the second beam.

9. The rail vehicle according to any of claims 5 to 8, wherein the processing unit is arranged to determine a velocity of the rail vehicle based on the information provided at the first time via the first beam and the information provided at the second time via the second beam.

10. A method for monitoring a rail vehicle comprising a processing unit that is arranged to control the on-board antenna according to any of the claims 1 to 4, wherein the at least two beams comprise a first beam and a second beam, the method comprising:

- receiving an information from a balise via the first beam at a first time,
- receiving the information from the balise via the second beam at a second time,
- determining the position of the rail vehicle based on the first information and on the second information.

11. The method according to claim 10, further comprising:

- determining the presence of the balise based on the information provided at the first time via the first beam and the information provided at the second time via the second beam.

12. The method according to any of claims 10 or 11, further comprising:

- determining a direction of movement of the rail vehicle based on the succession of the information provided at the first time via the first beam and the information provided at the second time via the second beam.

13. The method according to any of claims 10 to 12, further comprising:

- determining and canceling cross-talk based on the succession of the information provided at the first time via the first beam and the information provided at the second time via the second beam.

14. The method according to any of claims 10 to 13, further comprising:

- determining a velocity of the rail vehicle based on the information provided at the first time via the first beam and the information provided at the second time via the second beam.

15. A computer program product directly loadable into a memory of a digital computer, comprising software code portions for performing the steps of the method according to any of claims 10 to 14.

FIG 1

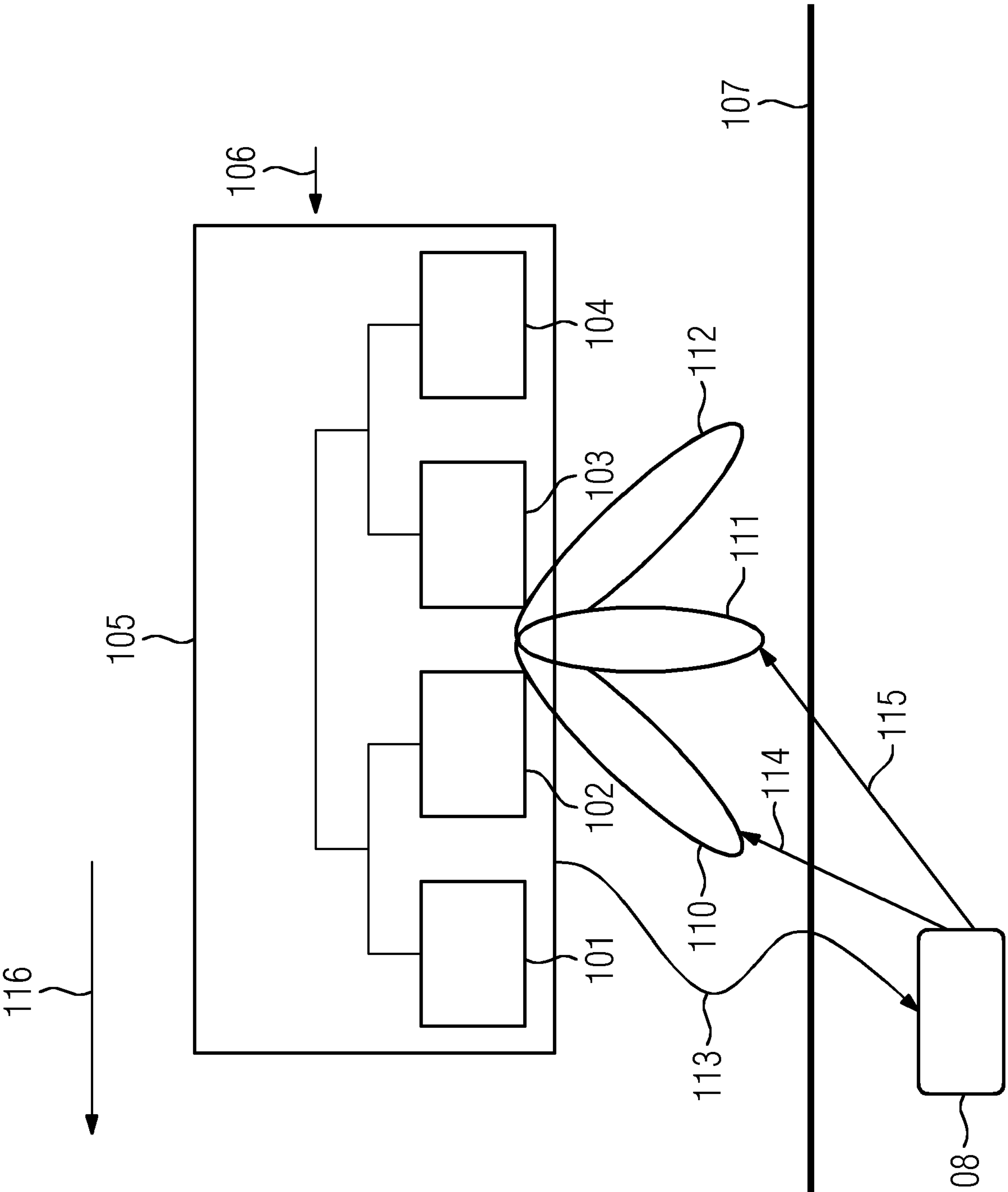
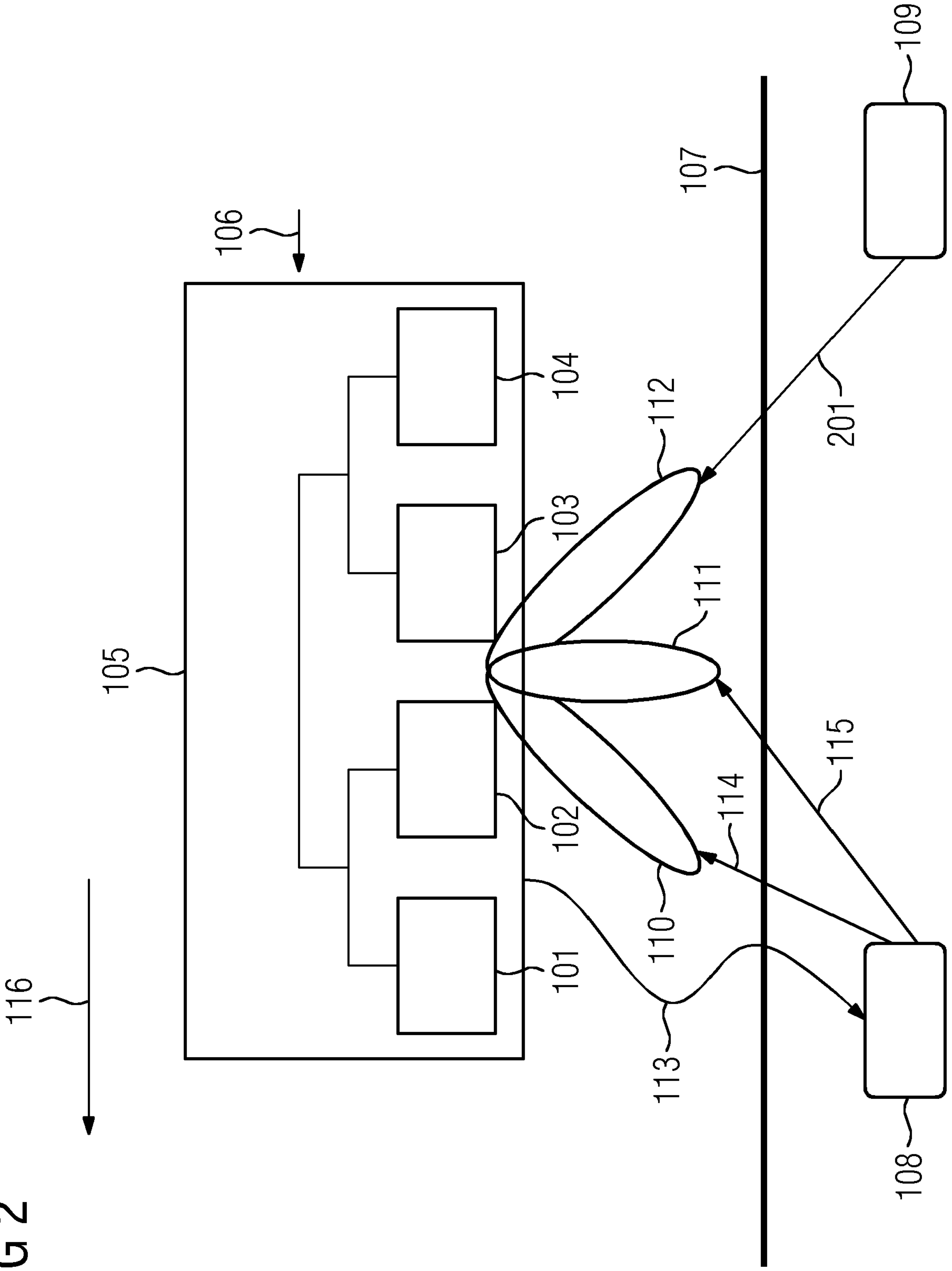


FIG 2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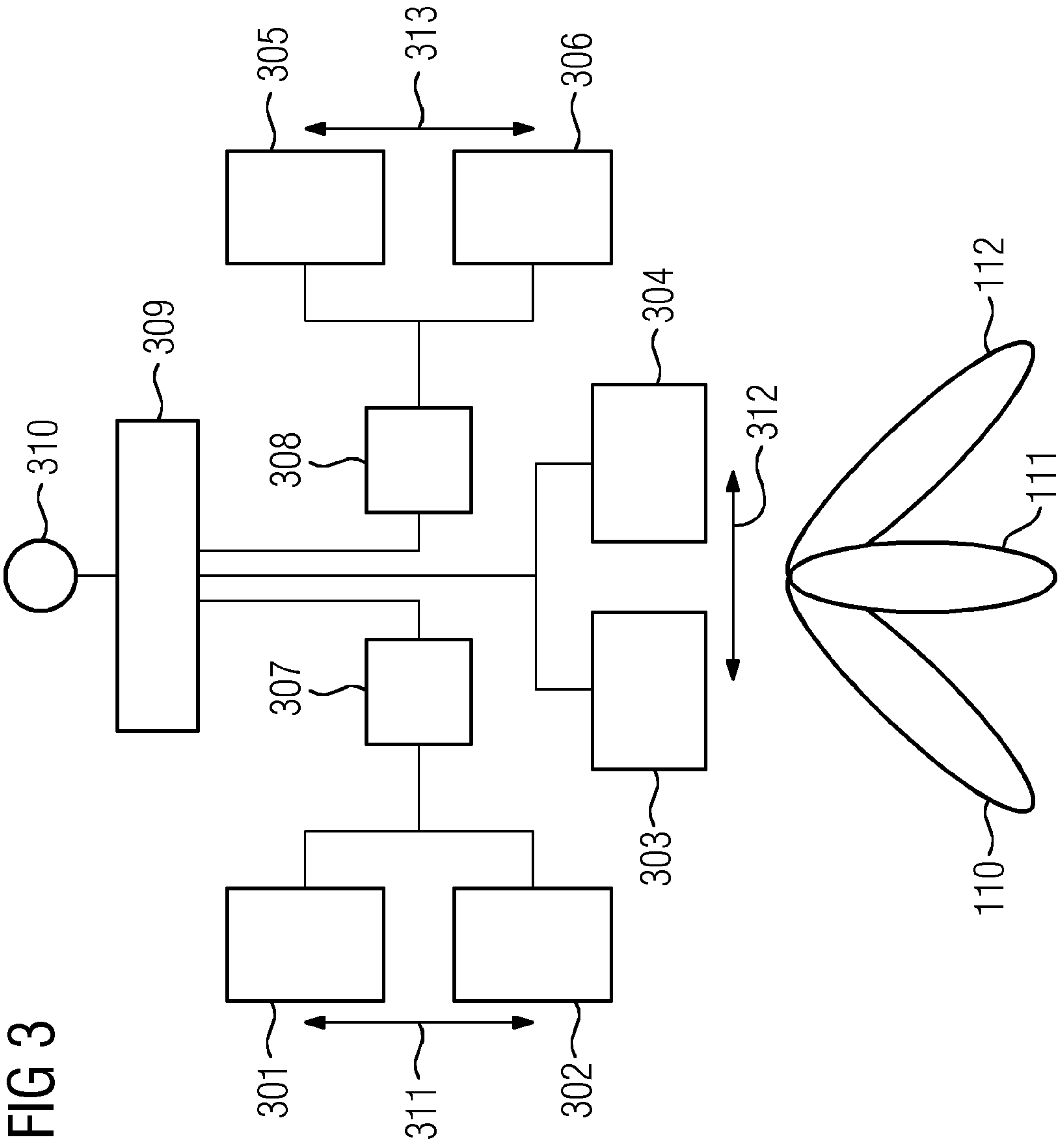

FIG 3

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EUROPEAN SEARCH REPORT

Application Number
EP 17 19 4052

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2016/001803 A1 (KIM JUNGTAI [KR] ET AL) 7 January 2016 (2016-01-07)	1,3-6,8, 10,11, 13,15	INV. B61L3/12 B61L25/02
Y	* paragraph [0010] - paragraph [0065]; figures 1-7 *	2,7,9, 12,14	
Y	FR 1 349 305 A (CSF) 17 January 1964 (1964-01-17) * page 2, column 1, paragraph 11 *	2	
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TECHNICAL FIELDS SEARCHED (IPC)

B61L

The present search report has been drawn up for all claims

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Place of search	Date of completion of the search	Examiner
Munich	1 March 2018	Mäki-Mantila, M

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO.

EP 17 19 4052

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report. The members are as contained in the European Patent Office EDP file on
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01-03-2018

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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

REFERENCES CITED IN THE DESCRIPTION

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