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- (81) Designated States (*unless otherwise indicated, for every kind of national protection available*): AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JO, JP, KE, KG, KH, KN, KP, KR, KW, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.
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(54) Title: 2D MIMO RADAR SYSTEM FOR VEHICLE

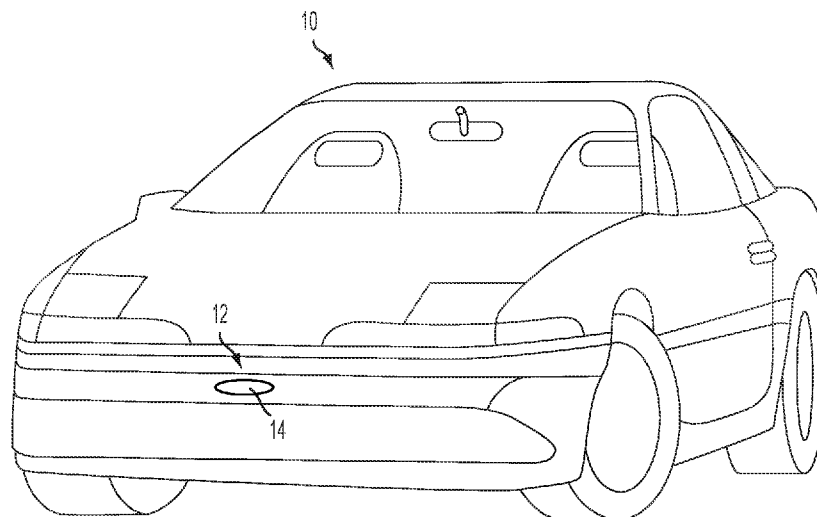


FIG. 1

(57) Abstract: A radar sensing system for a vehicle includes a radar sensor having a plurality of transmitting antennas and a plurality of receiving antennas. The transmitting antennas and the receiving antennas are arranged in multiple rows and columns of transmitting antennas and multiple rows and columns of receiving antennas. A control controls radar transmission by the transmitting antennas and receives outputs from the receiving antennas. The control applies two dimensional multiple input multiple output processing to outputs of the receiving antennas. With two dimensional multiple input multiple output processing applied to outputs of the receiving antennas, the transmitting antennas and the receiving antennas achieve an enhanced two dimensional virtual aperture.



EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV,
MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM,
TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW,
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Published:

- *with international search report (Art. 21(3))*
- *before the expiration of the time limit for amending the claims and to be republished in the event of receipt of amendments (Rule 48.2(h))*

2D MIMO RADAR SYSTEM FOR VEHICLE
CROSS REFERENCE TO RELATED APPLICATION

[0001] The present application claims the filing benefits of U.S. provisional application Ser. No. 62/359,913, filed Jul. 8, 2016, which is hereby incorporated herein by reference in its entirety.

FIELD OF THE INVENTION

[0002] The present invention relates generally to a vehicle sensing system for a vehicle and, more particularly, to a vehicle sensing system that utilizes one or more sensors at a vehicle to provide a field of sensing around the vehicle.

BACKGROUND OF THE INVENTION

[0003] Use of imaging sensors or ultrasonic sensors or radar sensors in vehicle sensing systems is common and known. Examples of such known systems are described in U.S. Pat. Nos. 8,013,780 and 5,949,331 and U.S. publication No. US-2010-0245066 and International Publication No. WO 2011/090484, which are hereby incorporated herein by reference in their entireties.

SUMMARY OF THE INVENTION

[0004] The present invention provides a driver assistance system or sensing system for a vehicle that utilizes one or more ranging sensors (such as radar sensors or the like) disposed at the vehicle to sense respective regions exterior of the vehicle, with each of the sensors or sensor units comprising a plurality of transmitters and receivers disposed at the vehicle. In a radar sensor of the present invention, a plurality of transmitting antennas and a plurality of receiving antennas are arranged as a two dimensional array of antennas. Outputs of the two dimensional array of antennas are communicated to a control, and the control applies two dimensional multiple input multiple output (MIMO) processing to outputs of the two dimensional array of antennas. Responsive to such processing, the control determines the presence of one or more objects exterior the vehicle and within the field of sensing of the array.

[0005] According to an aspect of the present invention, a radar sensing system for a vehicle includes a radar sensor having a plurality of transmitting antennas and a plurality of receiving antennas. The transmitting antennas and the receiving antennas are arranged in

multiple rows and columns of transmitting antennas and multiple rows and columns of receiving antennas. A control controls radar transmission by the transmitting antennas and receives outputs from the receiving antennas. The control applies two dimensional multiple input multiple output processing to outputs of the receiving antennas. With two dimensional multiple input multiple output processing applied to outputs of the receiving antennas, the transmitting antennas and the receiving antennas achieve an enhanced two dimensional virtual aperture. The plurality of transmitting antennas may be arranged in three rows, each row comprising four transmitting antennas, while the plurality of receiving antennas may be arranged in four columns, each column comprising at least four receiving antennas, with the columns of receiving antennas disposed between spaced apart rows of transmitting antennas, whereby the rows of transmitting antennas and the columns of receiving antennas function as 192 virtual receivers.

[0006] These and other objects, advantages, purposes and features of the present invention will become apparent upon review of the following specification in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 is a perspective view of a vehicle with a sensing system that incorporates a radar sensor in accordance with the present invention;

[0008] FIG. 2 is a diagram showing an antenna formation using two transmitting antenna and four receiving antenna;

[0009] FIG. 3 is a diagram showing the antennas of FIG. 2, with a virtual aperture when MIMO is applied;

[0010] FIG. 4 is a diagram of an antenna array with multiple transmitting antenna and multiple receiving antenna in accordance with the present invention; and

[0011] FIG. 5 is a diagram showing the virtual two-dimensional antenna aperture when 2D MIMO is applied with the antenna array of FIG. 4.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

[0012] A vehicle sensing system, such as a driver assist system, object detection system, parking assist system and/or alert system, operates to capture sensing data exterior of the vehicle and may process the captured data to detect objects at or near the vehicle and in the predicted path of the vehicle, such as to assist a driver of the vehicle in maneuvering the vehicle in a forward or rearward direction or to assist the driver in parking the vehicle in

a parking space. The system includes a processor that is operable to receive sensing data from multiple sensors and to provide an output to a control that, responsive to the output, generates an alert or controls an accessory or system of the vehicle, or highlights or overlays an alert on a display screen (that may be displaying video images captured by a single rearward viewing camera or multiple cameras providing forward, side or 360 degree surround views of the area surrounding the vehicle during a reversing or low speed maneuver of the vehicle).

[0013] Referring now to the drawings and the illustrative embodiments depicted therein, a vehicle 10 includes a driver assistance system or sensing system 12 that includes at least one radar sensor unit, such as a forward facing radar sensor unit 14 (and the system may optionally include multiple exterior facing radar sensors and/or other sensors, such as cameras or other sensors or the like, such as a rearward facing sensor at the rear of the vehicle, and a sideward/rearward facing sensor at respective sides of the vehicle), which sense regions exterior of the vehicle. The sensing system 12 includes a control or electronic control unit (ECU) or processor that is operable to process data captured by the sensor or sensors and may detect objects or the like. The data transfer or signal communication from the sensor to the ECU may comprise any suitable data or communication link, such as a vehicle network bus or the like of the equipped vehicle.

[0014] Automotive radars typically consist of multiple transmit and receive antennas in various formations, called antenna arrays. The total size (aperture) of such an antenna array formation defines the angular accuracy and angular discrimination capabilities of the radar sensing system. For radar systems, the term “resolution” is often used to describe the capability to discriminate two objects which are close to each other.

[0015] Some automotive radars use MIMO (Multiple Input Multiple Output) techniques to create an effective virtual antenna aperture, which is significantly larger than the real antenna aperture, and delivers much better angular resolution than conventional radars, such as, for example, conventional scanning radars. MIMO techniques are today just used in one dimension (typically horizontal). For example, a one dimensional array of transmitting antennas (such as two transmitting antennas) and receiving antennas (such as four receiving antennas) are linearly arranged in a single row (or column) and their real aperture is shown in FIG. 2. When MIMO techniques are applied, the virtual aperture (FIG. 3) achieved is greater than the real aperture.

- [0016]** In order to achieve angular accuracy and resolution in horizontal as well as in vertical, a two dimensional antenna array is used. A two dimensional radar is achieved by two scans, separately (time-multiplexed) in horizontal and vertical. A two dimensional radar can also be achieved by using MIMO when used separately for horizontal and vertical scan (also time-multiplexed).
- [0017]** Multi-dimensional MIMO techniques are used in communication systems today. When these techniques are applied to an automotive radar system, very accurate horizontal and vertical accuracy and resolution can be achieved at once (not time-multiplexed). Therefore, two dimensional (2D) MIMO techniques are applied on a two dimensional antenna array.
- [0018]** In the illustrated embodiment of the radar sensing system of the present invention, a two dimensional array of transmitting (Tx) antennas and receiving (Rx) antennas includes 12 transmitting (Tx) antennas and 16 receiving (Rx) antennas (FIG. 4) (which are configured for 2D MIMO processing and 192 virtual receivers). As shown in FIG. 4, the system may include three rows of four transmitting antennas and four columns of four receiving antennas arranged or configured to provide the desired or appropriate virtual aperture. When two dimensional MIMO techniques are applied to the array of antennas of FIG. 4, a two dimensional virtual antenna aperture is achieved (FIG. 5) that provides enhanced accuracy and resolution in both horizontal and vertical directions.
- [0019]** Thus, the two dimensional (2D) array of Tx antennas and Rx antennas is created on and occupies a two dimensional surface, such as a surface of a two dimensional antenna board or substrate or the like, with all Tx antennas and Rx antennas not in a single row or single column. Although shown and described as having three rows of four Tx antennas and four columns of four Rx antennas, other two dimensional arrangements of Tx and Rx antennas may be used, while remaining within the spirit and scope of the present invention. For example, the two dimensional arrangement of Tx and Rx antennas preferably includes at least four Tx antennas and six Rx antennas (providing at least twenty-four virtual receivers), more preferably at least eight Tx antennas and ten Rx antennas (providing at least eighty virtual receivers), and more preferably at least twelve Tx antennas and sixteen Rx antennas (providing at least 192 virtual receivers).
- [0020]** In a MIMO system, each transmitting antenna radiates an arbitrary waveform independently of the other transmitting antennas, and each receiving antenna can receive

these signals. Due to the different wave forms, the echo signals can be designated as coming from the respective transmitting antenna.

[0021] Thus, the system of the present invention provides enhanced radar sensing and processing, such as for detecting objects present in the field of sensing of the radar sensing system. For example, the control may apply two dimensional multiple input multiple output processing to outputs of the two dimensional array of antennas to detect objects present in the field of sensing of the two dimensional array of antennas, such as for a driving assistance system of the vehicle. For example, the driving assistance system may comprise an autonomous driving system, a semi-autonomous driving system, an automated parking system, a blind spot detection system, a cross traffic alert system, a lane change and merge aid system, an automatic emergency braking system, a pedestrian detection system, turn assist, and/or an intersection collision mitigation system. Optionally, the driving assistance system may also utilize image data captured by one or more exterior viewing cameras of the vehicle, and optionally the captured image data may be fused with sensed radar data to enhance detection of objects exterior of the vehicle. Optionally, the radar sensing system may provide an output to a control that, responsive to the output being indicative of detection of an object of interest exterior the vehicle (such as an object in the path of travel of the vehicle), generates an alert (such as a visual or audible or haptic alert to the driver or passenger of the vehicle) or controls an accessory or system of the vehicle (such as a steering system or braking system of the vehicle), or highlights or overlays an alert on a display screen (that may be displaying video images captured by a single rearward viewing camera or multiple exterior viewing cameras providing forward, side or 360 degree surround views of the area surrounding the vehicle during a reversing or low speed maneuver of the vehicle) to highlight the detected object in the displayed images to enhance the awareness of the driver as to the presence of the object.

[0022] The sensing system of the present invention may utilize aspects of the systems described in U.S. Pat. Nos. 9,599,702; 9,575,160; 9,146,898; 9,036,026; 8,027,029; 8,013,780; 6,825,455; 7,053,357; 7,408,627; 7,405,812; 7,379,163; 7,379,100; 7,375,803; 7,352,454; 7,340,077; 7,321,111; 7,310,431; 7,283,213; 7,212,663; 7,203,356; 7,176,438; 7,157,685; 6,919,549; 6,906,793; 6,876,775; 6,710,770; 6,690,354; 6,678,039; 6,674,895 and/or 6,587,186, and/or International Publication No. WO 2011/090484 and/or U.S. Publication No. US-2010-0245066 and/or U.S. patent applications, Ser. No. 15/619,627,

filed Jun. 12, 2017, Ser. No. 15/584,265, filed May 2, 2017, Ser. No. 15/467,247, filed Mar. 23, 2017, Ser. No. 15/446,220, filed Mar. 1, 2017, Ser. No. 15/420,238, filed Jan. 31, 2017, Ser. No. 15/467,247, filed Mar. 23, 2017, Ser. No. 15/446,220, filed Mar. 1, 2017, and/or Ser. No. 15/420,238, filed Jan. 31, 2017, and/or U.S. provisional applications, Ser. No. 62/375,161, filed Aug. 15, 2016, and/or Ser. No. 62/361,586, filed Jul. 13, 2016, which are hereby incorporated herein by reference in their entireties.

[0023] Optionally, the vision system may include a display for displaying images captured by one or more of the imaging sensors for viewing by the driver of the vehicle while the driver is normally operating the vehicle. Optionally, for example, the vision system may include a video display device, such as by utilizing aspects of the video display systems described in U.S. Pat. Nos. 5,530,240; 6,329,925; 7,855,755; 7,626,749; 7,581,859; 7,446,650; 7,338,177; 7,274,501; 7,255,451; 7,195,381; 7,184,190; 5,668,663; 5,724,187; 6,690,268; 7,370,983; 7,329,013; 7,308,341; 7,289,037; 7,249,860; 7,004,593; 4,546,551; 5,699,044; 4,953,305; 5,576,687; 5,632,092; 5,708,410; 5,737,226; 5,802,727; 5,878,370; 6,087,953; 6,173,501; 6,222,460; 6,513,252 and/or 6,642,851, and/or U.S. Publication Nos. US-2014-0022390; US-2012-0162427; US-2006-0050018 and/or US-2006-0061008, which are all hereby incorporated herein by reference in their entireties. Optionally, the vision system (utilizing the forward viewing camera and a rearward viewing camera and other cameras disposed at the vehicle with exterior fields of view) may be part of or may provide a display of a top-down view or bird's-eye view system of the vehicle or a surround view at the vehicle, such as by utilizing aspects of the vision systems described in International Publication Nos. WO 2010/099416; WO 2011/028686; WO 2012/075250; WO 2013/019795; WO 2012/075250; WO 2012/145822; WO 2013/081985; WO 2013/086249 and/or WO 2013/109869, and/or U.S. Publication No. US-2012-0162427, which are hereby incorporated herein by reference in their entireties.

[0024] Changes and modifications in the specifically described embodiments can be carried out without departing from the principles of the invention, which is intended to be limited only by the scope of the appended claims, as interpreted according to the principles of patent law including the doctrine of equivalents.

CLAIMS:

1. A radar sensing system for a vehicle, said radar sensing system comprising:
a radar sensor having a plurality of transmitting antennas and a plurality of receiving antennas;
wherein said transmitting antennas and said receiving antennas are arranged in multiple rows and columns of transmitting antennas and multiple rows and columns of receiving antennas;
a control, wherein said control controls radar transmission by said transmitting antennas and receives outputs from said receiving antennas;
wherein said control applies two dimensional multiple input multiple output processing to outputs of said receiving antennas; and
wherein, with two dimensional multiple input multiple output processing applied to outputs of said receiving antennas, said transmitting antennas and said receiving antennas achieve an enhanced two dimensional virtual aperture.
2. The radar sensing system of claim 1, wherein said plurality of transmitting antennas are arranged in at least two rows, each row comprising at least two transmitting antennas.
3. The radar sensing system of claim 2, wherein said plurality of receiving antennas are arranged in at least two columns, each column comprising at least two receiving antennas.
4. The radar sensing system of claim 3, wherein said at least two columns of receiving antennas are disposed between spaced apart rows of transmitting antennas.
5. The radar sensing system of claim 1, wherein said plurality of transmitting antennas are arranged in three rows, each row comprising four transmitting antennas.
6. The radar sensing system of claim 5, wherein said plurality of receiving antennas are arranged in four columns, each column comprising at least four receiving antennas.

7. The radar sensing system of claim 6, wherein said columns of receiving antennas are disposed between spaced apart rows of transmitting antennas.
8. The radar sensing system of claim 7, wherein said rows of transmitting antennas and said columns of receiving antennas function as 192 virtual receivers.
9. The radar sensing system of any preceding claim, wherein each transmitting antenna radiates an arbitrary waveform signal independently of other transmitting antennas, and wherein each receiving antenna receives the signals reflected off objects in the field of sensing of said radar sensing system.
10. The radar sensing system of claim 9, wherein, due to different waveforms in the transmitted signals, the reflected signals can be designated as originating from a particular transmitting antenna.
11. The radar sensing system of any preceding claim, wherein said control applies two dimensional multiple input multiple output processing to outputs of said receiving antennas to detect objects present in the field of sensing of said radar sensor.
12. The radar sensing system of claim 11, wherein said control, responsive to detection of an object, at least one of (i) generates an alert, (ii) controls an accessory of the vehicle, and (iii) highlights a portion of images displayed on a display screen of the vehicle that is displaying video images captured by one or more exterior viewing cameras of the vehicle.
13. The radar sensing system of any preceding claim, wherein said radar sensing system provides detection for a driving assistance system of the vehicle.
14. The radar sensing system of claim 13, wherein the driving assistance system comprises a system selected from the group consisting of an autonomous driving system, a semi-autonomous driving system, an automated parking system, a blind spot detection system, a cross traffic alert system, a lane change and merge aid system, an automatic

emergency braking system, a pedestrian detection system, turn assist, and an intersection collision mitigation system.

15. The radar sensing system of claim 14, wherein the driving assistance system also utilizes image data captured by one or more exterior viewing cameras of the vehicle, and wherein captured image data is fused with sensed radar data to enhance detection of objects exterior of the vehicle.

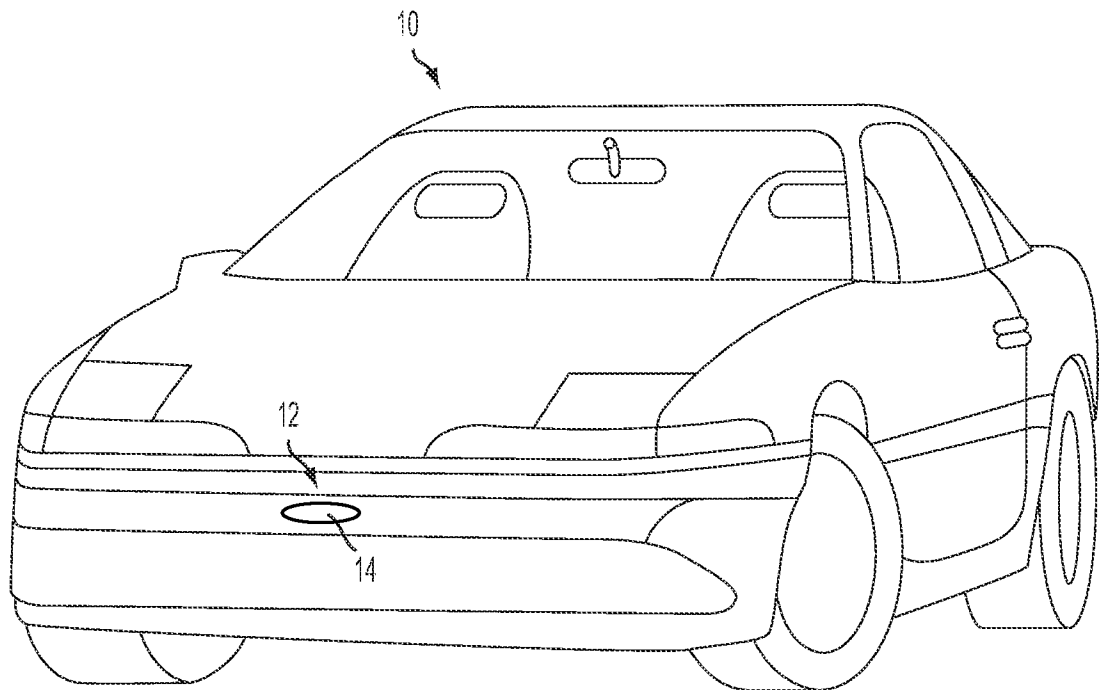


FIG. 1

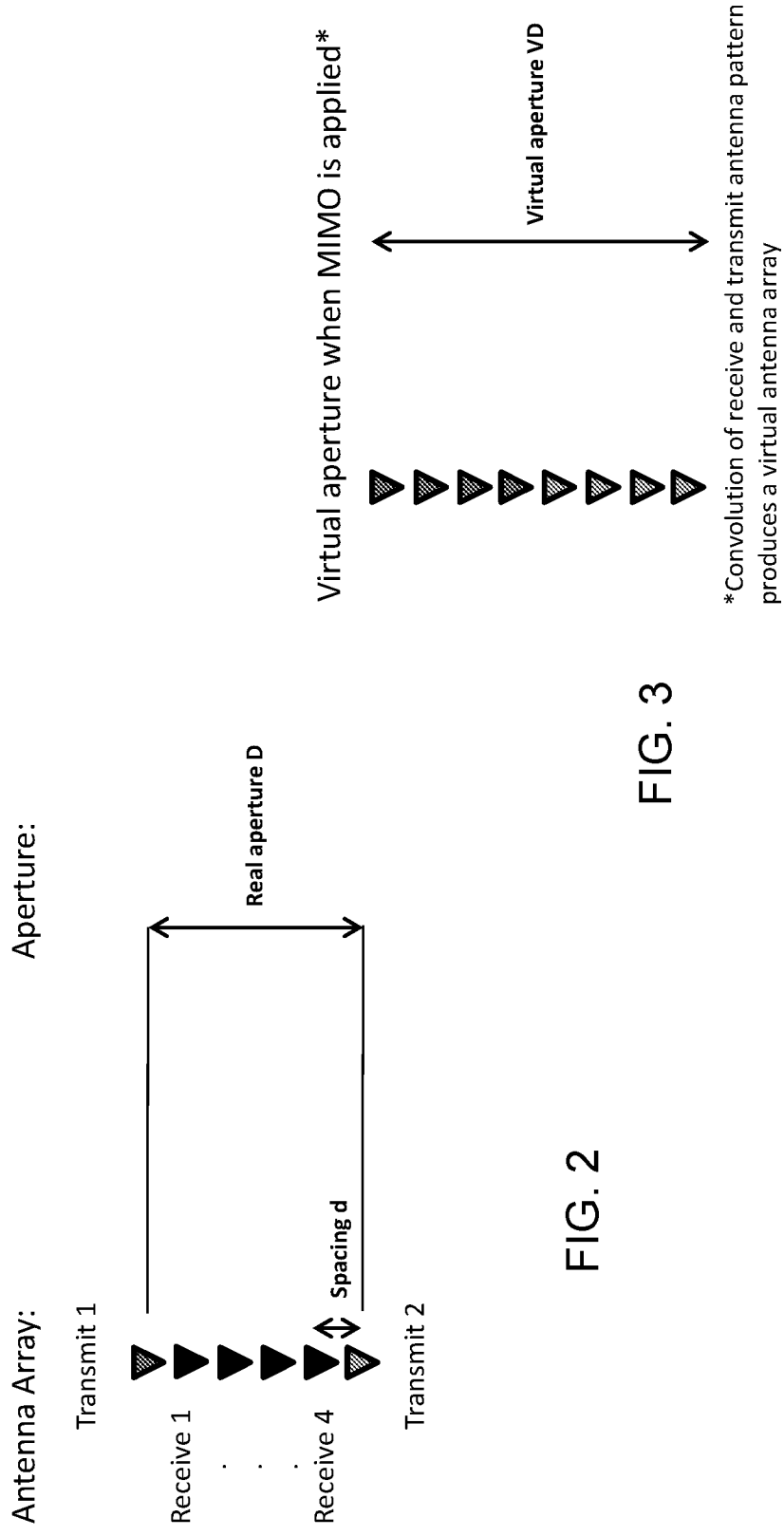
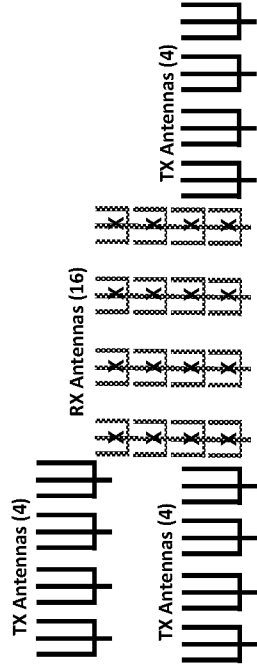


FIG. 2

FIG. 3

FIG. 4

Antenna Array:



Virtual two-dimensional antenna aperture when 2D MIMO is applied:

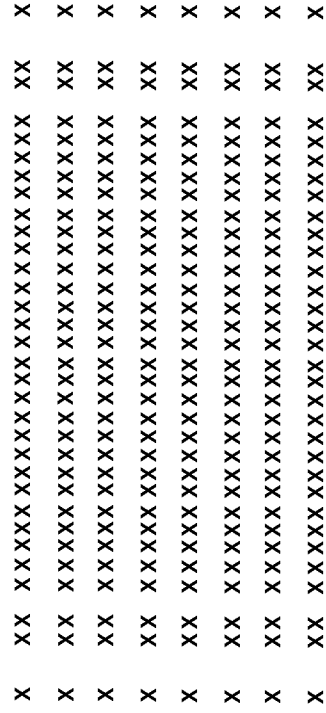


FIG. 5

INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB17/54120

A. CLASSIFICATION OF SUBJECT MATTER

IPC - H04B 7/02; G01S 13/02, 13/88 (2017.01)

CPC - H04B 1/38, 7/024, 7/0413, 7/0663; G01S 13/02, 13/88, 13/66

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

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

See Search History document

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

See Search History document

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

See Search History document

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X --- Y --- A	US 2016/0131752 A1 (NXP, B.V.) 12 May 2016; paragraphs [0026], [0043], [0069].	1-4 ----- 5-7, 9/1-9/7, 10/9/1-10/9/7 ----- 8, 9/8, 10/9/8
Y	WO 2016/002221 A1 (DENSO CORPORATION) 7 January 2016; paragraphs [0019], [0034].	5-7, 9/1-9/7, 10/9/1-10/9/7
Y	US 2008/0158056 A1 (SHIMA, N) 3 July 2008; paragraphs [0073], [0083].	5-7, 9/5-9/7, 10/9/5-10/9/7
Y	US 2004/0032366 A1 (LAGENBERG, J) 19 February 2004; paragraph [0031].	6-7, 9/6-9/7, 10/9/6, 10/9/7
Y --- A	US 7522095 B1 (WASIEWICZ, R et al.) 21 April 2009; claim 46.	7, 9/7, 10/9/7 ----- 8, 9/8, 10/9/8

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

* Special categories of cited documents:

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

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

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

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

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

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

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

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

"&" document member of the same patent family

Date of the actual completion of the international search

7 November 2017 (07.11.2017)

Date of mailing of the international search report

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Name and mailing address of the ISA/

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/IB17/54120

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

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

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

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

3. Claims Nos.: 11-15
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

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

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

1. As all required additional search fees were timely paid by the applicant, this international search report covers all searchable claims.
2. As all searchable claims could be searched without effort justifying additional fees, this Authority did not invite payment of additional fees.
3. As only some of the required additional search fees were timely paid by the applicant, this international search report covers only those claims for which fees were paid, specifically claims Nos.:

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

Remark on Protest

- The additional search fees were accompanied by the applicant's protest and, where applicable, the payment of a protest fee.
- The additional search fees were accompanied by the applicant's protest but the applicable protest fee was not paid within the time limit specified in the invitation.
- No protest accompanied the payment of additional search fees.