(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
23 November 2017 (23.11.2017)

(10) International Publication Number
WO 2017/199125 A1

(51) International Patent Classification:
G01S 13/02 (2006.01) *G01S 7/02* (2006.01)
G01S 13/32 (2006.01)

(21) International Application Number: PCT/IB2017/052670

(22) International Filing Date: 08 May 2017 (08.05.2017)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
15/157,425 18 May 2016 (18.05.2016) US

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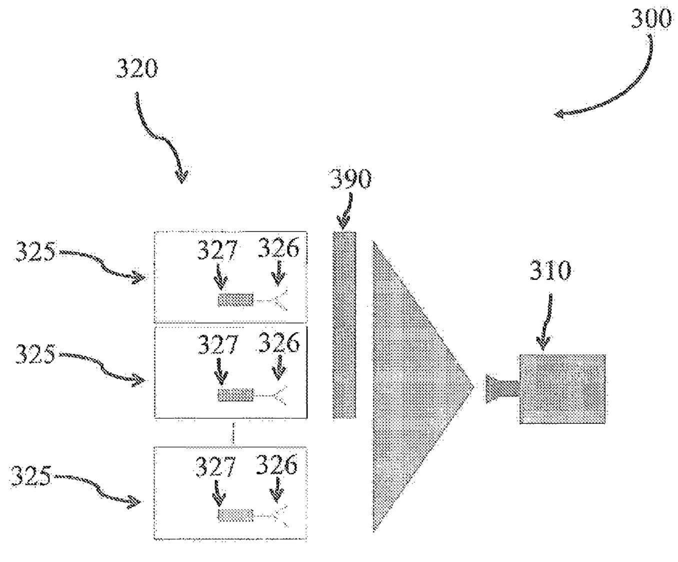
(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DJ, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KH, KN, KP, KR,

(54) Title: RANGE-INDEPENDENT RESOLUTION RADAR

FIG. 3



(57) Abstract: An apparatus for imaging that is not range dependent for resolution is provided. Arrays of cells comprised of antennas and true delays can be played behind a target. The signal reflected by the individual cells provides information on whether the cell is blocked by the target. Additional information can be determined from the radar returns, such as material properties and target thickness. Similar structures can be constructed to act as wireless barcodes.

WO 2017/199125 A1

[Continued on next page]

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.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, 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, KM, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report (Art. 21(3))*

RANGE-INDEPENDENT RESOLUTION RADAR

TECHNICAL FIELD

[0001] The invention is generally directed to radar systems. In particular it provides an apparatus, method and system suitable for creating range-independent resolution radar.

BACKGROUND

[0002] The spatial resolution of radar systems typically depends on the beamwidth, the size of the radar antennas, and the distance between the radar and the target. Consequently, there is typically a tradeoff between these factors and achievable resolution in radar sensing.

[0003] Traditionally, spatial resolution could be increased by increasing the antenna size. For example, as the antenna aperture size is increased, the beamwidth of the antenna (i.e., 3 dB attenuation with respect to the peak) decreases. An approximate expression for the inverse relation between the antenna size (D) and the 3 dB beamwidth (BW) for a horn antenna is $BW=70\lambda/D$, where λ is the wavelength. As a result of the decreased beamwidth, the spot size on the target decreases as well, enabling the detection of smaller features on the target. The enlargement of the antenna size needs to be done on either or both the transmitter's and the receiver's antennas of the radar in order to improve the radar resolution. However, the use of large antennas, such as large reflector dishes or arrays of antenna elements, can increase the system cost, size, and weight. In addition, it may be necessary to mechanically rotate or move the antenna or target in order to observe different features on the target such that the relevant area on the target would be illuminated. Larger antennas can be made by constructing phased arrays that use, for example, digital beamforming, or multi-static methods. However, phased array antennas add complexity in the form of individual feeds, transceivers, and phase shifters, and/or processing sections.

[0004] Spatial resolution can also be increased by moving the radar system closer to the target. FIG. 1 shows the effect of antenna size, target distance, and beamwidth on the spot size on the target. For a given antenna size (D) and 3 dB beamwidth (BW), the spot size on the target (X) depends on the distance (R) between the target and the radar antenna. The spot size can be approximated as $X=2R\tan[\lambda/(2D)]$, where λ is the wavelength. However, moving the antenna closer to the target is not always a practical approach, as one cannot always control the distance between the radar and the target. In addition, the spot size does not decrease with the radar-target distance when the distance becomes shorter than the far-field distance $D^{2/}\lambda$. In fact, the minimum spot size close to the antenna is of the order of the antenna aperture size itself, as is shown in FIG. 2.

[0005] Super-resolution techniques can also be used to improve the resolution of radar systems. Super-resolution techniques, however, may require increased processing power and sophisticated algorithms. In addition, many super-resolution techniques require a high signal-to-noise ratio for efficient processing. Other techniques, such as monopulse can also be used to increase the resolution.

[0006] What is needed is a radar system with resolution independent of the range to the target. Therefore, there is a need in the art to address the aforementioned problem.

SUMMARY

[0007] Viewed from a first aspect, the present invention provides an apparatus for imaging, the apparatus comprising: a radar transmitter configured to transmit a radar signal; a first cell comprising a first antenna and a first delay element, wherein the first cell is configured to receive the radar signal from the radar transmitter and to retransmit the radar signal after a first known time delay from the first delay element; and a radar receiver configured to receive the retransmitted radar signal from the first cell.

[0008] Viewed from a further aspect, the present invention provides a method for imaging, the method comprising: transmitting a first radar signal by a radar transmitter; receiving at least some portion of the radar signal at a first antenna of a first cell; generating, by a first delay element, a first time delayed signal based on the received at least some portion of the radar signal; retransmitting the first time delayed signal by the first antenna of the first cell; receiving the at least some portion of first time delayed signal by a radar receiver; and constructing an image, wherein constructing the image comprises determining the absence of a target based on the presence of the first time delayed signal and the presence of a target based on the absence of the first time delayed signal.

[0009] Viewed from a further aspect, the present invention provides a system for imaging, the system comprising: a radar, wherein the radar comprises: a radar transmitter configured to generate a radar signal, and a radar receiver; and a cell array, wherein the cell array comprises: a first cell, wherein the first cell comprises a first antenna and a first delay element connected to the first antenna, wherein the first antenna and the first delay element are configured to receive the radar signal, generate a first time delayed radar signal by the first delay element, and transmit the first time delayed radar signal such that at least some portion of the first time delayed radar signal is incident on the radar receiver, and a second cell, wherein the second cell comprises a second antenna and a second delay element connected to the second antenna, wherein the second antenna and the second delay element are configured to receive the radar signal, generate a second time delayed radar signal by the second delay element, and transmit the second time delayed radar signal such that at least some portion of the second time delayed radar signal is incident on the radar receiver.

[0010] The present invention relates to improving the performance of radar, spectroscopy and imaging systems by (i) performing single or multi-pixel imaging with a single fixed beam radar regardless of the size of the radar-antenna, and (ii) providing a super-resolution of the target edges, at the order of a wavelength or less, that is independent from the target distance.

[0011] The invention, in an embodiment, further relates to a novel technique for radar imaging that achieves super-resolution of a target profile edges by placing an array of cells containing true delays or lumped delays behind the target. In an embodiment, the resolution of the radar is determined, in part, by the size of the cells. Typical cells can be of the order of a wavelength, and the resolution of the radar is of the same order. This resolution can be achieved regardless of the size of the illuminating and receiving radar antennas, and regardless of the distance between the radar and the target. The cell structure is, in an embodiment, composed of an antennas (e.g., a horn, open ended waveguide, or patch antenna) connected to a lumped-delay (such as phase shifter, capacitors, inductors, etc.) with e.g. short circuit after the lumped element or true delay element (such as a waveguides, printed microstrip line, stripline, coaxial cable, coplanar waveguide, etc.) with generally varying length or delay for each cell by e.g. short-circuiting the delay element at the desired length. The cells are placed behind the target, and the overall design does not require significant changes in the radar system itself. With the described apparatus, the spatial resolution of the radar together with the cells is determined by the size of the cells and not by the size of the radar antennas or by the radar-target distance. The cell structure can be used with any radar system, such as continuous wave, pulsed, or other.

[0012] These and other features, aspects, and advantages of the present invention will become understood with reference to the following description, appended claims, and accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

[0013] Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

FIG. 1 is a diagram showing the relation of the spot size from a radar to the distance to the target and the beamwidth, in accordance with the prior art;

FIG. 2 is a diagram showing the near-field and far-field components of the radar beam, in accordance with the prior art;

FIG. 3 is a schematic diagram of the range independent resolution radar system, according to an embodiment of the present invention;

FIG. 4 is a schematic of the cell array with eighteen open-ended waveguides as antennas where each antenna is connected to a waveguide with different length by shortening the waveguide at the desired position, according to an embodiment the present invention;

FIG. 5 is a plot of the resulting beat frequencies of a continuous wave implementation of an embodiment of the present invention;

FIG. 6A is a schematic of a target present in front of the cell array, according to an embodiment of the present invention;

FIG. 6B is a plot of the beat frequencies present for a frequency-modulated continuous-wave radar, according to an embodiment of the present invention;

FIG. 6C is a reconstructed target image, according to an embodiment of the present invention;

FIG. 7 is a schematic of a compact structure with flat waveguide meander tunnels, according to an embodiment of the present invention;

FIG. 7A is a schematic diagram of a top layer of a device, according to an embodiment of the present invention, with nine antennas;

FIG. 7B is a schematic diagram of a middle signal distribution layer of a device, according to an embodiment of the present invention;

FIG. 7C is a schematic diagram of a bottom true delay line layer of a device, according to an embodiment of the present invention;

FIG. 7D is a schematic diagram of a multilayer device, according to an embodiment of the present invention;

FIG. 8A is a schematic view of eight open ended waveguide antennas connected to eight waveguides with different lengths that are illuminated by an incident field, according to an embodiment of the present invention;

FIG. 8B is a plot of field intensities of a wave incident on the range independent resolution radar system's cell array, according to an embodiment of the present invention;

FIG. 8C is a retransmitted signal directivity plot, according to an embodiment of the present invention;

FIG. 9 is a barcode like device, according to an embodiment of the present invention; and

FIG. 10 is range independent resolution radar system incorporating lenses, according to an embodiment of the present invention.

DETAILED DESCRIPTION

[0014] In the following detailed description of the preferred embodiments, reference is made to the accompanying drawings, which form a part hereof, and within which are shown by way of illustration specific embodiments by which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the invention.

[0015] A schematic diagram of the range independent resolution radar system, according to an embodiment of the present invention, is shown in FIG. 3. The range independent radar system 300 is composed of a radar 310 and an cell array 320. The radar 310 comprises a transmitter and a receiver. The target 390 is placed between the transmitter 310 and the cell array 320. Each cell 325 comprises a cell antenna 326 and a true delay 327. The cell antenna 326 can be any type of antenna suitable for transmitting and receiving signals in the radar frequency of operation, and may be an open ended waveguide, horn, patch, dipole, slot, miniaturized antenna, or reduced size dielectric surrounded antenna. The true delay 327 can be implemented as a microstrip line, stripline, waveguide, coplanar waveguide, or any other transmission line that can guide the incoming energy received by the cell-antenna and reflect it back to the radar. Other delay elements, such as lumped elements, can be substituted for the true delay 327. Depending on the signal to noise ratio capabilities of the radar, the gain of each antenna, the losses of the transmission line and the coupling between cells and the transmission line, one can reduce the antenna size and crowd the transmission line with no inherent physical limit determined by the wavelength.

[0016] Note that the radar transmitting antenna illuminating the target and the radar receiving antenna capturing the reflections from the target can be different or could be implemented by the same antenna. Also note that in FIG. 3 the target does not necessary block all of the cells. The apparatus, system, and method of embodiments of the present invention are applicable to all the cases where it is possible to put such cells behind the target. The target may also move within the area in front of the cells, and the imaging system may generate a series of images at various times when the time the target is present. Each cell produces a delay caused by its different length. For continuous-wave radars, such as frequency-modulated continuous-wave radar, each delay would be translated to different beat frequency f_b in the radar receiver. For pulsed radars, the different delay will cause the reflected signal to arrive at a different times t_r at the radar receiver. The cell will have a known delay from the true delay 327, by which it will delay the radar signal. The radar receiver can determine which cells are blocked based on the presence and/or amplitude of signal corresponding to the known time delay of the cell. Starting from a case where the array is illuminated by the radar's signal and there is no target obstructing the path, the radar will measure the delay associated with all the cells in the array. In case one or more cells are blocked by the target, the f_b or t_r associated with these cells will not appear at the radar output. Since the position of the cells can be known and predetermined, a high resolution image of the targets profile edges or the entire target can be formed. This high resolution is enabled regardless of the radar antenna size, target-radar distance, and without the need for traditional super-resolution methods.

[0017] FIG. 4 shows an embodiment of the cell array 320 according to an embodiment of the present invention with eighteen open-ended waveguides as antennas where each antenna is connected to a waveguide with different length by shortening the waveguide at the desired position. When illuminating this structure by, for example, by a frequency-modulated continuous-wave radar with signal whose frequency spectrum has bandwidth B around f_0, eighteen beat frequencies will be generated in the radar receiver in correspondence with the delay of each cell. A plot of the resulting beat frequencies 510, according to an embodiment of the present invention, can be seen in FIG. 5. Note that the cell array 320 structure can contain any number of cells. This number can be chosen, for example, by considering the typical cell size, the target size and the frequency of operation.

[0018] The range resolution of the radar is given as $\Delta L=c/(2B)$, where c is the speed of light and B, the bandwidth of the radar. Therefore, the difference in length between cells should be larger or equal to ΔL. Although the example here is for frequency-modulated continuous-wave radar, the same structure can be used with any continuous wave, pulsed, or other types of radar. In the case of pulsed radar, the length difference of each cell will generate different delays in the radar receiver.

[0019] FIG. 6A shows a schematic of a target 390 present in front of the cell array 320 according to an embodiment of the present invention. The target 390 will block some of the cells and other cells of the cell array 320 may be left open. When illuminating the target and the cells with a beam whose size is equal or larger than the cell array, only some of the beat frequencies 510 (f_b) or delays (t_r) that corresponds to the cells that were left open will produce corresponding signals at the radar receiver. The beat frequencies produced for a frequency-modulated continuous-wave radar, according to an embodiment of the present invention, are shown in FIG. 6B. Since the positions of the cells are known and pre-determined, an image 650 of the target can be formed, as shown in FIG. 6C.

[0020] The distance between the target and the cells is not limited to any particular value. However, close distances are preferred so as to avoid diffraction effects in which cells that are blocked from direct view by the target would manage to reflect some of the energy back to the radar.

[0021] The collective field reflected back from all the cells in the structure is, in fact, an aperture field of an antenna array. Therefore, one may randomly distribute the lengths of the true delays of each cell in order to create random phase distribution on this aperture. In such a way, we minimize the possibility of beam shifting that will reduce the power propagating towards the receiving antenna of the radar.

[0022] Other configurations of the array are also possible. In an embodiment, the straight and long waveguides that appear in FIG. 4 can be replaced by a more compact structure with flat waveguide meander tunnels according to an embodiment of the present invention, as shown in FIG. 7D. The top layer 710 of the device is shown in FIG. 7A. This top layer 710 has a four by four set of open ended waveguides acting as the cell antennas. The middle layer 720 of the device is shown in FIG. 7B. This layer has distributing tunnels from the cell antennas to the true delays, which are waveguide tunnels in this embodiment. In this embodiment, the waveguide tunnels are thin tunnels. A bottom layer 730 of true delays can be seen in FIG. 7C. Note that the combined delay of a waveguide tunnel of the middle layer 720 and the true delay of the bottom layer 730 gives the known delay value of the true delay of the cell array 320. All of the layers combined can be seen in FIG. 7D, which produce the cell array 320.

[0023] FIG. 8A shows a cell array 320 made up of eight open ended waveguide antennas connected to eight waveguides with different lengths that are illuminated by an incident field, according to an embodiment of the present invention. The illumination represents the signal transmitted by a radar. The different lengths of the waveguides are achieved by short-circuiting each waveguide to the desired length. The spatial pattern of the reflected wave is shown in FIG. 8B. This spatial pattern shows that each cell captured the illuminating wave and retransmitted a wave according to the length of the true delay. Illuminating a multi-cell structure with a radar signal, such as a pulsed signal or a continuous wave signal, generates the various output signals, such as delayed pulses or beat frequencies, from which the radar image or target profile can be produced. Note that the differences in length among the waveguides were chosen, in an embodiment, such that the retransmitted energy was steered by 30 degrees, as is seen in FIG. 8C. That is, a phase shift in each of the cells can be purposely introduced to change the direction of the retransmitted signal. However, the cells can be distributed randomly in terms of phase shifts between the cells in order to avoid beam steering of the reflected wave.
The relatively high scattered field intensities behind the waveguides seen in FIG. 8B can be reduced as desired. This reduction can be achieved by placing radar absorbing materials around the cells aperture.

[0024] In addition to the frequencies reflected from the target and the structure, the amplitude of the reflected wave can be used for attaining additional information about the target. In the case of a frequency-modulate continuous-wave radar, the frequency received corresponding to a particular cell may have lower amplitude when the cell is partially blocked. The degree of the attenuation can aid in determining the extent of blockage by the target. The attenuated signal can also be used to further enhance the spatial resolution beyond the cell size. The signal attenuation can also be used for detecting material properties. For highly conducting metallic target, the blocked cells will emit little or no energy. If the target is made of other, only partially absorbing materials, cells that are blocked by the target may be able to reflect some of the energy back to the radar. In this way, the system can be used to characterize the material composition of the target, particularly at the radar operation frequency. Note that a partially transparent object will not obstruct the radar beam, thereby allowing the corresponding returned signal (e.g., beat frequency components in frequency-modulated continuous-wave radar or delayed pulses in pulsed radar) to appear, although attenuated. If the amplitude information is considered, the target object's image is still generated by noting that the corresponding frequencies return with lower power due to attenuation. The attenuated signal can provide information on the transparency of the object, which is determined by the material, its thickness, and its shape.

[0025] The system can also aid in the determination of the target thickness. The characteristics of the returned signal will be dependent on the target thickness for some materials. In the case of cells that partially blocked or partially transparent, reference frequency signals and additional beat frequencies signals that correspond to energy travelling back and forth multiple times to the cell are generated. This information can be used to determine the target thickness in these cases. Furthermore in the case of continuous wave radar, cells that are partially blocked may generate frequencies that correspond to waves travelling back and forth multiple times to and from the cells before they are received by the radar. These frequencies will indicate that they are not fully blocked, improving the spatial resolution to a size below the cell size. Spatial resolution better than the wavelength can be obtained if the distance of the blocking object from the delay line aperture is shorter than a wavelength, and if the aperture size of the delay lines itself is smaller than a wavelength. The limit to the spatial resolution is the aperture dimension as long as the delay line is able to guide a wave at the given small aperture dimension.

[0026] The cell array 320 may also be configured to create a barcode like device. The barcode like device, according to an embodiment of the present invention, is shown in FIG. 9. This low-profile device has nine patch antennas and nine printed transmission lines with each transmission line connected to an antenna. By using a phased array or a focal plane array, the beam of the radar can be focused or directed towards any of the cells separately. In this case, other applications such as a wireless barcode can be implemented. Each cell can be connected to a certain length and repetitions between true delay lengths are allowed since the beam is pointed to a specific cell and read its delay, generating a numerical value based on the delay. These numerical values can be combined into a barcode value. Since the total number of possibilities, even with low number of cells, is very large, a barcode like device can be implemented.

[0027] A method for improving the resolution for targets smaller than the cell array, according to an embodiment of the present invention, is shown in FIG. 10. If a small target is placed in front of a multi-cell structure and blocks only small number of cells, the resolution of the formed image can be improved by adding a first lens 910 and a second lens 920, placing the target 390 between the lenses, and locating the cell array 320 after the second lens 920 as shown. In this way, the target's projected shape on the cells is larger, and more cells are effectively blocked. This lens system leads to improvement in the image resolution in comparison to the case without the lenses.

[0028] Although specific embodiments of the present invention have been described, it will be understood by those of skill in the art that there are other embodiments that are equivalent to the described embodiments. Accordingly, it is to be understood that the invention is not to be limited by the specific illustrated embodiments, but only by the scope of the appended claims.

[0029] While the foregoing written description of the invention enables one of ordinary skill to make and use what is considered presently to be the best mode thereof, those of ordinary skill will understand and appreciate the existence of variations, combinations, and equivalents of the specific embodiment, method, and examples herein. The invention should therefore not be limited by the above described embodiment, method, and examples, but by all embodiments and methods within the scope of the invention. To the extent necessary to understand or complete the disclosure of the present invention, all publications, patents, and patent applications mentioned herein are expressly incorporated by reference therein to the same extent as though each were individually so incorporated.

[0030] Having thus described exemplary embodiments of the present invention, those skilled in the art will appreciate that the within disclosures are exemplary only and that various other alternatives, adaptations, and modifications may be made within the scope of the present invention. Accordingly, the present invention is not limited to the specific embodiments as illustrated herein, but is only limited by the following claims.

CLAIMS

1. An apparatus for imaging, the apparatus comprising:

a radar transmitter configured to transmit a radar signal;

a first cell comprising a first antenna and a first delay element, wherein the first cell is configured to receive the radar signal from the radar transmitter and to retransmit the radar signal after a first known time delay from the first delay element; and

a radar receiver configured to receive the retransmitted radar signal from the first cell.

2. The apparatus of claim 1, wherein the first delay element is a true delay.

3. The apparatus of either of the preceding claims, wherein the radar receiver performs the steps of:

determining a first pixel value, wherein the first pixel value is based on the first known time delay and an amplitude of the received retransmitted radar signal.

shading an image location of the first pixel value based on the location of the first cell.

4. The apparatus of any of the preceding claims, wherein the radar transmitter is a continuous wave transmitter, and the first cell is configured to produce a known beat frequency at the radar receiver from the transmitted radar signal and the retransmitted radar signal.

5. The apparatus of any of claims 1 to 3, wherein the radar signal transmitter is a pulsed transmitter, and the radar receiver constructs an image of the target by determining the amplitude of the retransmitted radar signal with the first known time delay.

6. The apparatus of any of the preceding claims, further comprising a second cell, wherein the second cell comprises a second antenna and a second delay element, and wherein the second cell is configured to receive the radar signal from the radar transmitter and to retransmit the radar signal after a second known time delay from the second delay element.

7. The apparatus of any of the preceding claims, wherein the first antenna comprises a waveguide antenna and the first delay element comprises a waveguide.

8. The apparatus of claim 1, wherein the first antenna comprises a patch antenna and the first delay element comprises a microstrip line.

9. The apparatus of claim 1, further comprising a first lens and a second lens, wherein the first lens and second lens are located between the first cell and the radar transmitter.

10. A method for imaging, the method comprising:

transmitting a first radar signal by a radar transmitter;

receiving at least some portion of the radar signal at a first antenna of a first cell;

generating, by a first delay element, a first time delayed signal based on the received at least some portion of the radar signal;

retransmitting the first time delayed signal by the first antenna of the first cell;

receiving the at least some portion of first time delayed signal by a radar receiver; and

constructing an image, wherein constructing the image comprises determining the absence of a target based on the presence of the first time delayed signal and the presence of a target based on the absence of the first time delayed signal.

11. The method of claim 10, wherein the first delay element is a true delay.

12. The method of either of claims 10 or 11, wherein the radar constructing a radar image comprises:

determining a first pixel value, wherein the first pixel value is based on the first time delayed signal; and

shading the image location of the first pixel value based on a first location of the first cell antenna.

13. A system for imaging, the system comprising:

a radar, wherein the radar comprises:

a radar transmitter configured to generate a radar signal, and a radar receiver; and

a cell array, wherein the cell array comprises:

a first cell, wherein the first cell comprises a first antenna and a first delay element connected to the first antenna, wherein the first antenna and the first delay element are configured to receive the radar signal, generate a first time delayed radar signal by the first delay element, and transmit the first time delayed radar signal such that at least some portion of the first time delayed radar signal is incident on the radar receiver, and a second cell, wherein the second cell comprises a second antenna and a second delay element connected to the second antenna, wherein the second antenna and the second delay element are configured to receive the radar signal, generate a second time delayed radar signal by the second delay element, and transmit the second time delayed radar signal such that at least some portion of the second time delayed radar signal is incident on the radar receiver.

14. The system of claim 13, wherein the first delay element is a true delay, and the second delay element is a true delay.

15. The system of either of claims 13 or 14, wherein the radar receiver constructs a radar image by determining a first pixel value, wherein the first pixel value is based on the first time delayed radar signal;

determining a second pixel value, wherein the second pixel value is based on the second time delayed radar signal; and

arranging the first pixel value and the second pixel value into an image by shading a first image location of the first pixel value based on the location of the first cell and shading a second image location of the second pixel value based on the location of the second cell.

16. The system of any of claims 13 to 15, wherein:

the radar transmitter is configured to direct a first beam at the first cell and direct a second beam at the second cell; and

the radar receiver is configured to record a first numerical value based on the first time delayed radar signal, to record a second numerical value based on the second time delayed radar signal, and to combine the first numerical value and second numerical value into an electronic barcode value.

17. The system of any of claims 15 to 16, wherein the first antenna and the second antenna are located on a first layer, and the first true delay and the second true delay are located on a second layer.

18. The system of claim 17, wherein the first antenna is connected to the first true delay by a first thin tunnel waveguide, and the second antenna is connected to the second true delay by a second thin tunnel waveguide.

19. The system of any of claims 13 to 18, wherein the radar transmitter is a continuous wave transmitter, the first cell is configured to produce a first known beat frequency at the radar receiver, and the second cell is configured to produce a second known beat frequency at the radar receiver.

20. The system of any of claims 13 to 19, wherein the first antenna comprises a waveguide antenna and the first delay element comprises a waveguide, and wherein the second antenna comprises a waveguide antenna and the second delay element comprises a waveguide.

FIG. 1

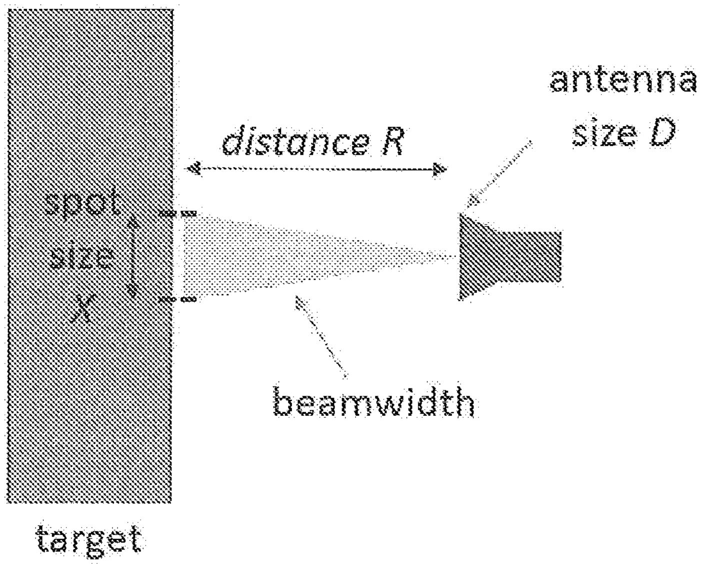


FIG. 2

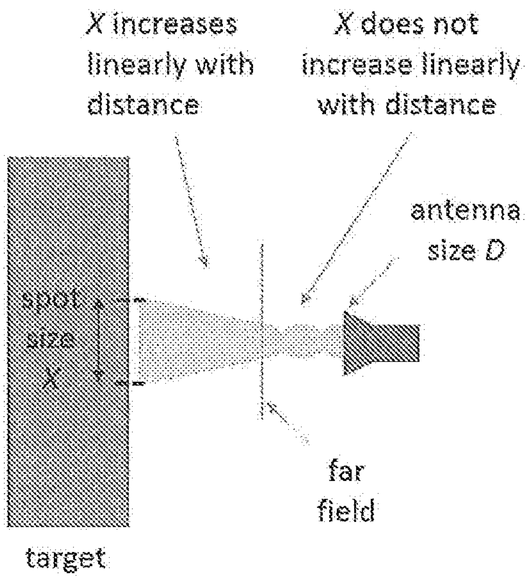

X increases linearly with distance
X does not increase linearly with distance
antenna size D
spot size X
far field
target

FIG. 3

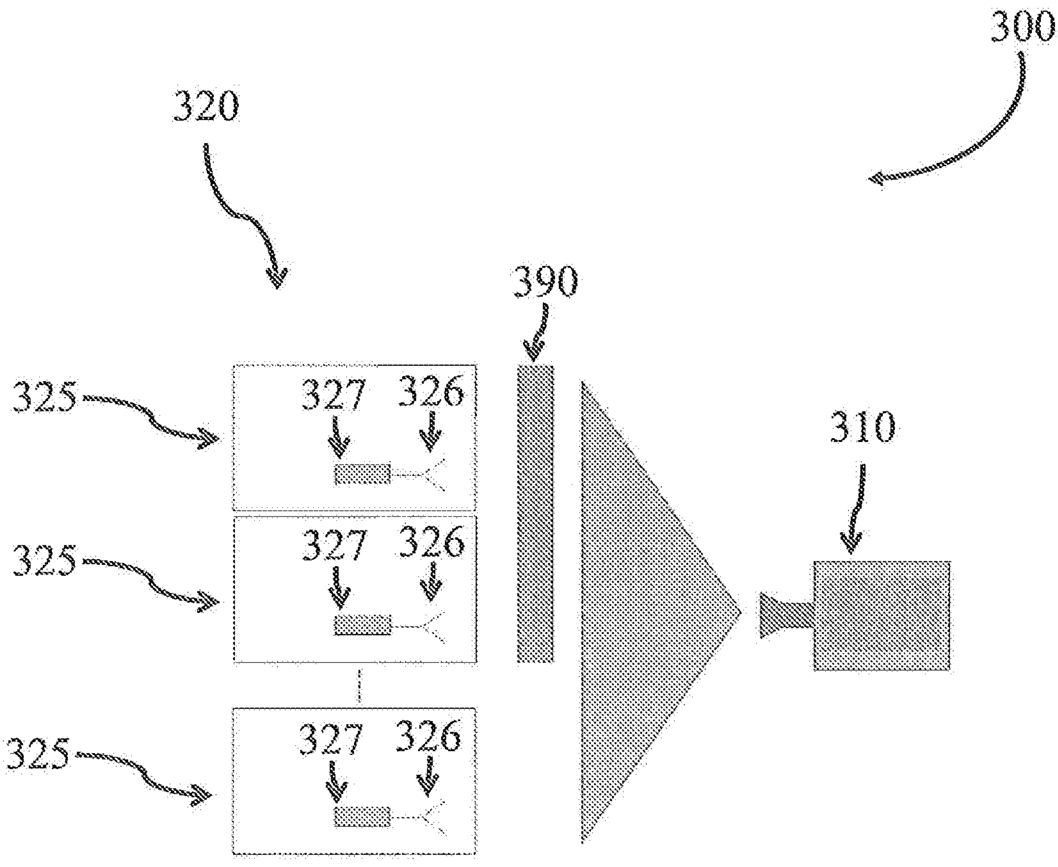


FIG. 4

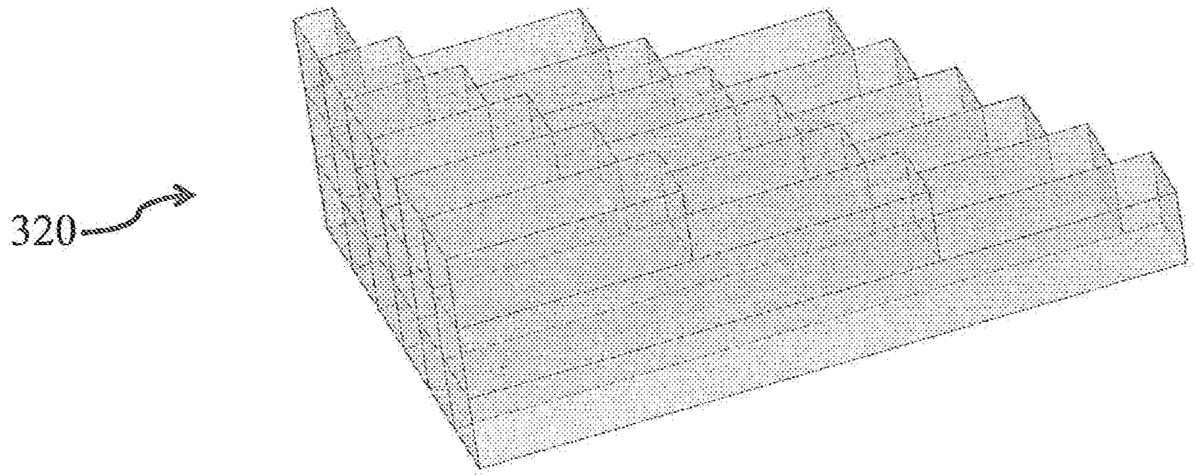


FIG. 5

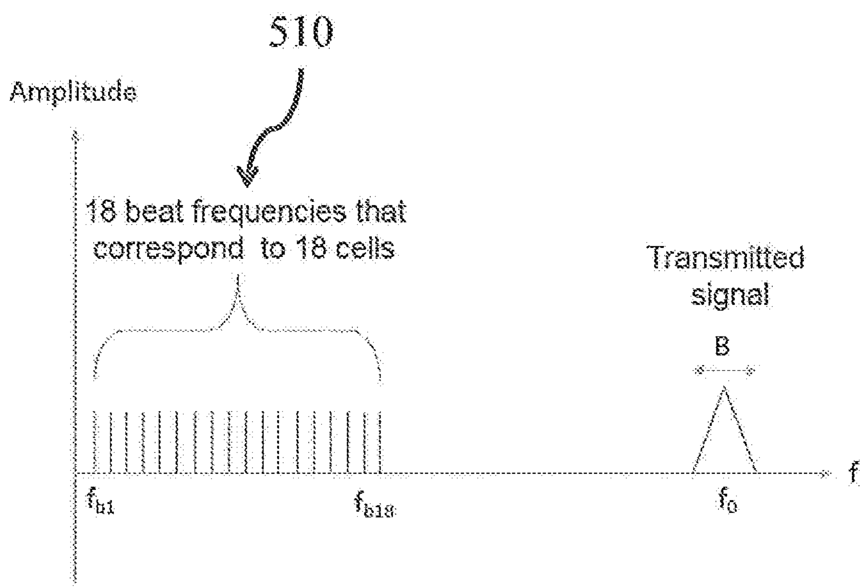

510
Amplitude
18 beat frequencies that correspond to 18 cells
Transmitted signal
B
f
f_{b1}
f_{b18}
f_0

FIG. 6A

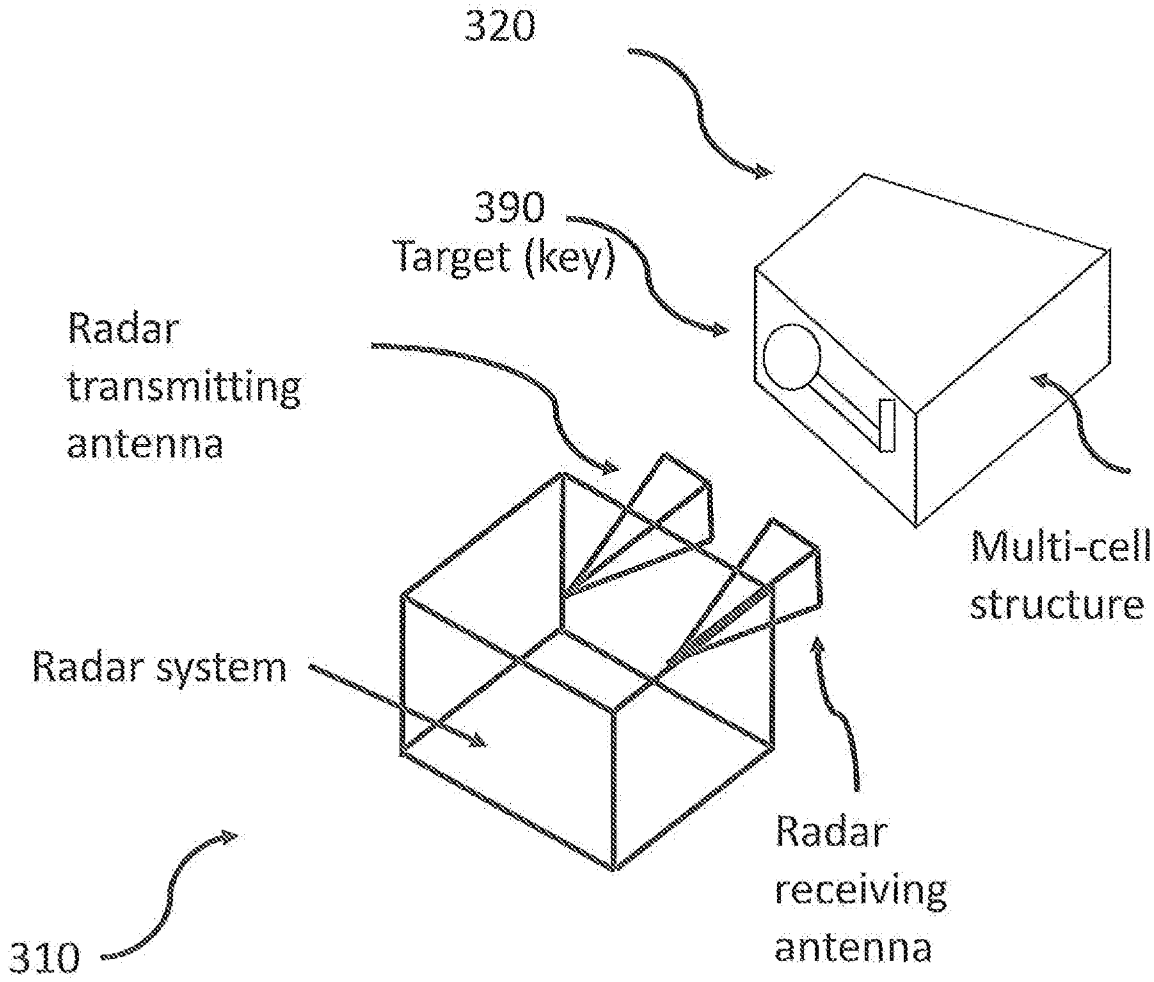
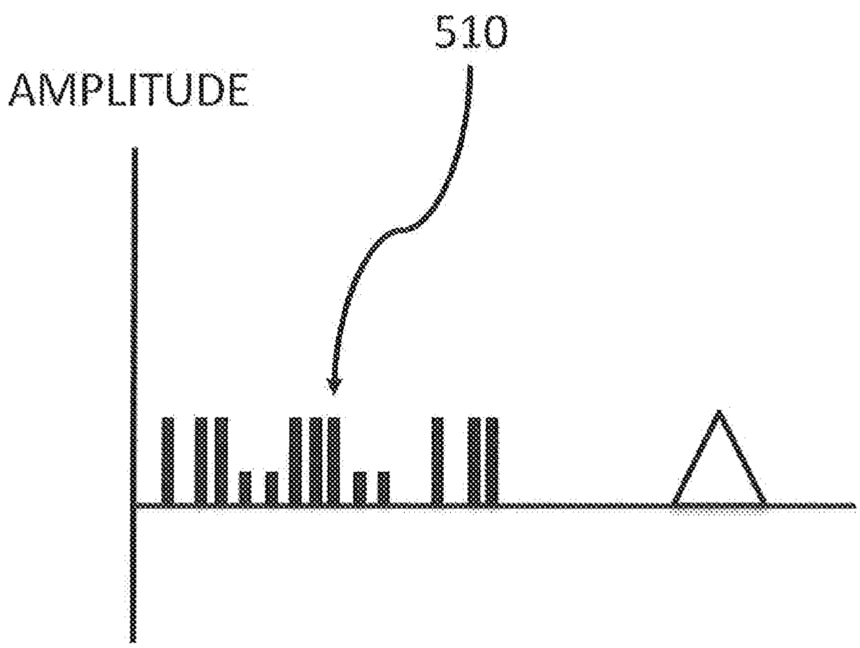

320
390
Target (key)
Radar
transmitting
antenna
Multi-cell
structure
Radar system
Radar
receiving
antenna
310

FIG. 6 B



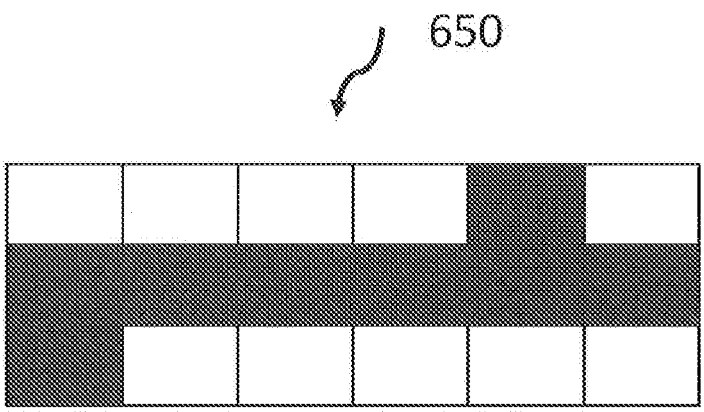


FIG. 6 C

FIG. 7A

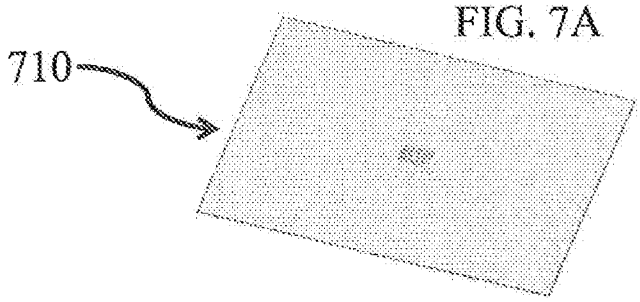


FIG. 7B

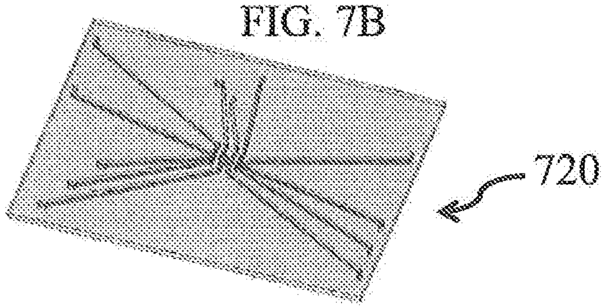


FIG. 7C

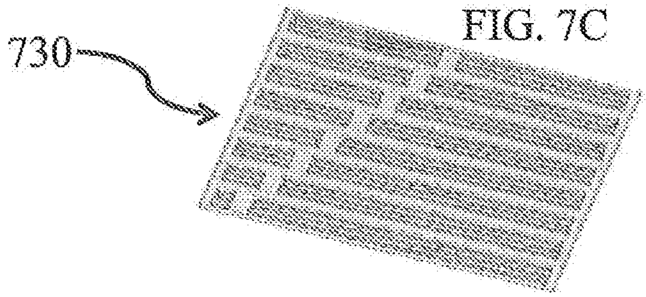


FIG. 7D

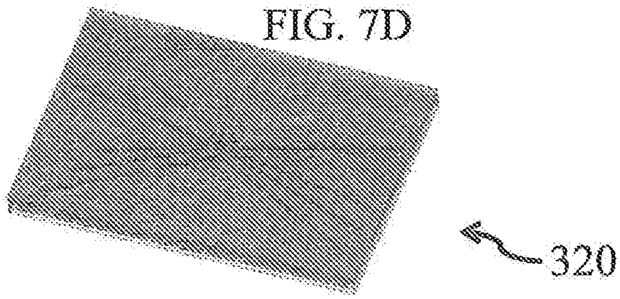
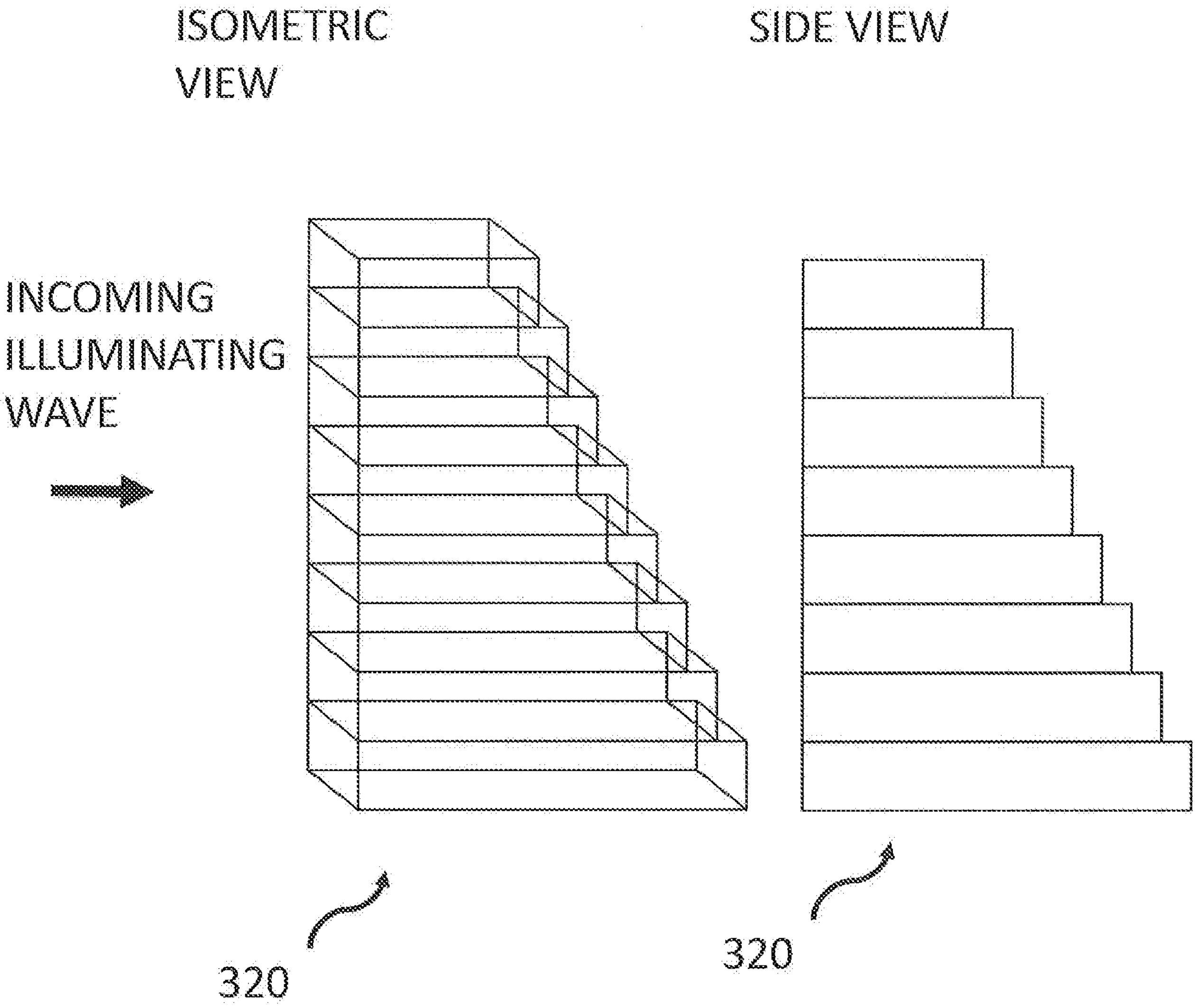


FIG. 8A


ISOMETRIC
VIEW
SIDE VIEW
INCOMING
ILLUMINATING
WAVE
320
320

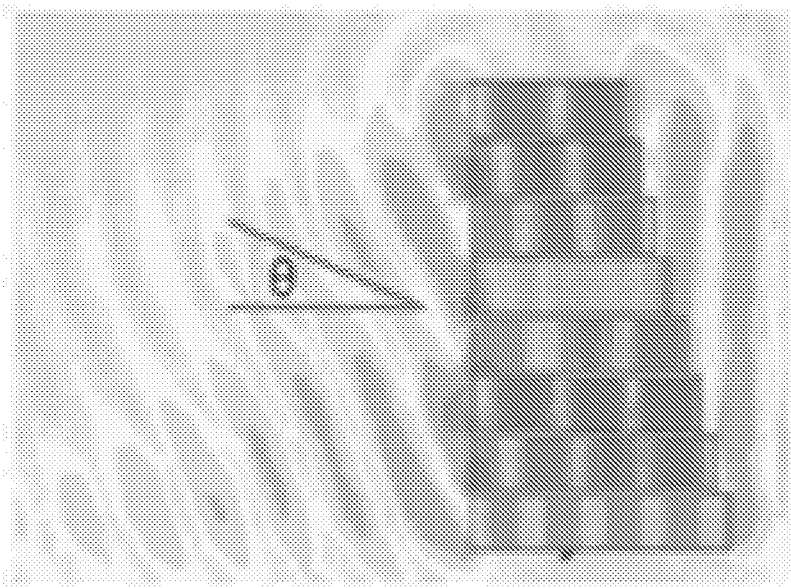


FIG. 8B

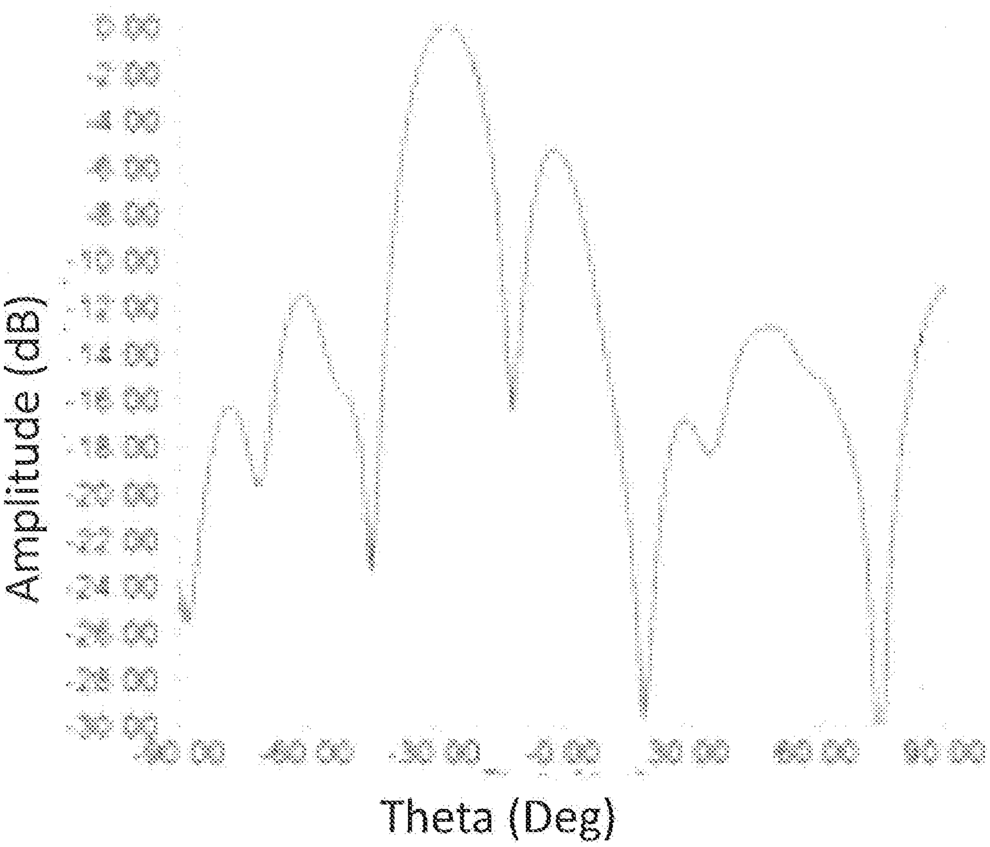
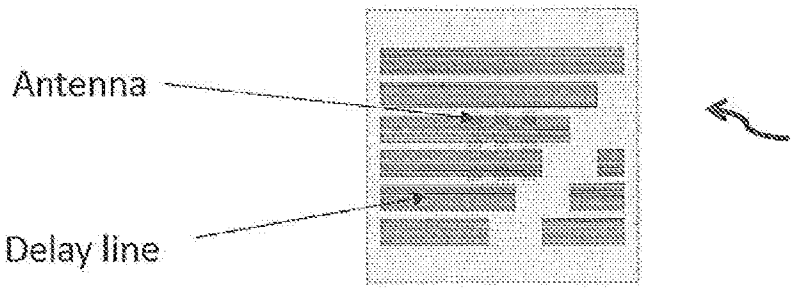


FIG. 8C

FIG. 9



320

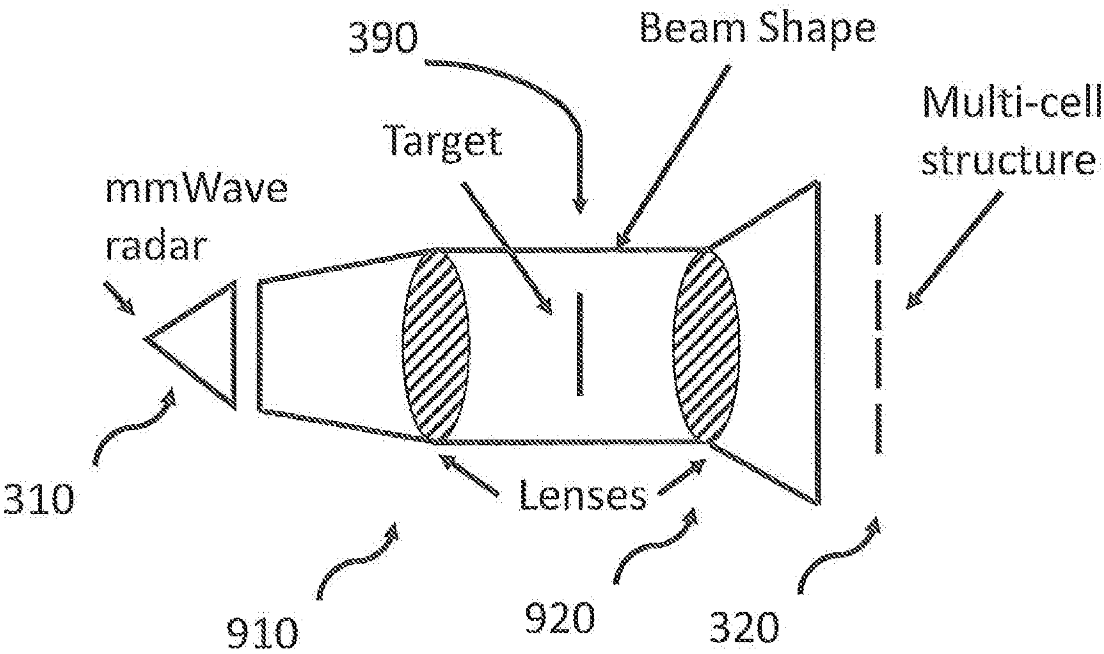

390
Beam Shape
Multi-cell
structure
Target
mmWave
radar
310
Lenses
910
920
320

FIG. 10

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IB2017/052670

A. CLASSIFICATION OF SUBJECT MATTER

G01S 13/02(2006.01)i; G01S 13/32(2006.01)i; G01S 7/02(2006.01)i

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)

G01S

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

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

VEN, CNABS, CNTXT: radar, imaging, range, resolution, continuous, wave, cell, time, delay, frequency, beat, pixel, amplitude

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2014266866 A1 (NOKIA CORP.) 18 September 2014 (2014-09-18) paragraphs [0003] to [0098] of the description, figures 1 and 2	1-20
A	CN 103744076 A (UNIV. HOHAI) 23 April 2014 (2014-04-23) the whole document	1-20
A	US 6414746 B1 (ADVANCED SCIENT CONCEPTS INC.) 02 July 2002 (2002-07-02) the whole document	1-20
A	US 6133989 A (ADVANCED SCIENT CONCEPTS INC.) 17 October 2000 (2000-10-17) the whole document	1-20
A	CN 103941243 A (UNIV. ELECTRONIC SCIENCE & TECH.) 23 July 2014 (2014-07-23) the whole document	1-20

☐ 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	Date of mailing of the international search report
18 August 2017	**24 August 2017**

Name and mailing address of the ISA/CN	Authorized officer
STATE INTELLECTUAL PROPERTY OFFICE OF THE P.R.CHINA **6, Xitucheng Rd., Jimen Bridge, Haidian District, Beijing 100088** **China**	**ZHANG,Yaling**
Facsimile No. **(86-10)62019451**	Telephone No. **(86-10)62085722**

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IB2017/052670

Patent document cited in search report			Publication date (day/month/year)	Patent family member(s)			Publication date (day/month/year)
US	2014266866	A1	18 September 2014	US	9285461	B2	15 March 2016
CN	103744076	A	23 April 2014	CN	103744076	B	06 July 2016
US	6414746	B1	02 July 2002		None		
US	6133989	A	17 October 2000		None		
CN	103941243	A	23 July 2014	CN	103941243	B	17 August 2016