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(54) **Title**: A METHOD FOR MITIGATING RAIN CLUTTER INTERFERENCE IN MILLIMETER-WAVE RADAR DETECTION

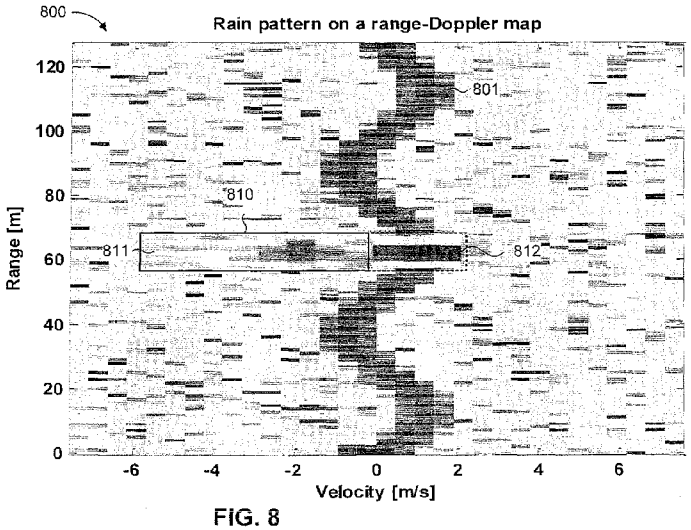


FIG. 8

(57) **Abstract**: Method for object detection in rain environment with W-band radar detection system. Radar data of region of interest is obtained, and range-velocity map generated. Initial threshold values are calculated in the range-velocity map. A rain condition is established in the region of interest based on amount of cells in the range velocity map exceeding initial threshold values. If rain condition is present, rain cells and object cells are designated in the range-velocity map, the designated rain cells forming a rain cell pattern. Rain cell threshold values are calculated in rain cell pattern. A first object cluster is detected within the rain cell cluster, a second object cluster is detected outside the rain cell pattern in the vicinity of the first object cluster, and the first object cluster is merged with the second objet cluster to form a unified object pattern. Required information associated with the object of interest is obtained.

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A METHOD FOR MITIGATING RAIN CLUTTER INTERFERENCE IN MILLIMETER-WAVE RADAR DETECTION

FIELD OF THE DISCLOSED TECHNIQUE

The disclosed technique generally relates to millimeter-wave radar, and more particularly, to mitigating rain clutter interference in millimeter-wave radar detection.

BACKGROUND OF THE DISCLOSED TECHNIQUE

Radar transceivers implemented in a single chip using radio frequency integrated circuit (RFIC) technology have been developed for various automotive applications, such as adaptive cruise control systems, collision avoidance systems, collision warning systems, lane change assistance systems, and parking assistance systems. W-band millimeter-wave radar systems, which transmit electromagnetic waves in the frequency range of 75GHz-110GHz, offer better range-resolution characteristics than lower frequency microwave radar, and can penetrate fog, smoke and other atmospheric obscurants significantly better than infrared sensors. A low attenuation atmospheric window of the W-band spectral range increases the operational range for a given transmitted power. Due to these features and the emerging low cost and compact device technologies, W-band millimeter-wave radar systems are

employed in a wide range of commercial, military and scientific applications, including robotic vision, speed and range measurements for industrial uses, air turbulence measurements, and security applications.

One drawback of millimeter-wave radar systems is that the radio waves in this frequency range are reflected by raindrops, since the wavelength of the radio waves is of the same order of magnitude as the raindrop dimensions. This is likely to increase the false alarm rate (FAR) of an outdoor radar detection system during rainy conditions, unless the radar detection system differentiates between radar reflection from raindrops and radar reflection from an object of interest. The degree of attenuation in the radar signal resulting from rain is directly correlated to the severity of the rainfall. Therefore, the effect of rain clutter in a millimeter-wave radar detection system is more prominent during heavier rain conditions. Reference is now made to Figure 1, which is a schematic illustration of a graph, generally referenced 10, of the atmospheric attenuation of radio waves as a function of frequency, for different rain conditions. The vertical axis of graph 10 represents attenuation in units of dB/km. The horizontal axis of graph 10 represents frequency ranging between 3GHz-100GHz and displayed on a logarithmic scale. Each graph line, of the seven graph lines depicted, is associated with a different rain condition. The rain conditions vary in severity between a drizzle (least severe rain condition), a light rain, a medium rain, a heavy rain, and

a tropical downpour (most severe rain condition). Considering the W-band frequency range of 75GHz-100GHz, it is observed that the atmospheric attenuation ranges between approximately 0.2dB/km during drizzle conditions to nearly 100dB/km during tropical downpour conditions. Yet a more substantial effect of rainfall over the atmospheric attenuation of millimeter-wave radar is that the transmitted radio waves are reflected by the rain. It is thus apparent that the wave reflections from raindrops must be taken into account in order to provide reliable object detection with millimeter-wave radar systems.

The substantial signal intensity detected from raindrop reflections can significantly increase the system false alarm rate (i.e., number of false positive detections) if the rain is not identified and accounted for. Reference is now made to Figure 2, which is a schematic illustration of a graph, generally referenced 20, of the receiver radar signal intensity in the presence of rain, as a function of range. The horizontal axis of graph 20 represents range in units of meters (m), and the vertical axis of graph 20 represents the signal intensity level at the radar receiver in units of decibels (dB). It is apparent from the intensity of signal 22 that signal 22 was reflected from an object in the scene. If threshold value 21 is derived by a common processing method that provides a threshold value mostly determined by the system thermal noise and regular

reflections from the ground surface, several reflections from the raindrops will exceed the threshold value and create false alarms.

The rain clutter interference problem has been addressed in the past, in attempting to obtain robust detection performance of outdoor radar systems. For instance, U.S. Patent No. 6,127,965 to McDade et al, entitled “Method and apparatus for rejecting rain clutter in a radar system”, discloses a method and apparatus for detecting the presence of objects in a vehicle operator's blind spots. The side facing Frequency Modulated Continuous Wave (FMCW) radar detects targets even when operated in rainy weather conditions and will not generate false warnings due to rain clutter. The radar system indicates that a target is detected if and only if any part of the target is within the detection zone. By rejecting targets that are closer than the minimum range to the antenna, false alarms due to rain clutter are radically reduced.

U.S. Patent No. 6,937,185 to Collazo et al, entitled “Rain versus target discrimination for Doppler radars”, discloses a method for better discriminating targets in rain conditions. A range-frequency map is calculated from the radar data, and cells associated with signals having a higher spectral power than noise, corresponding to reflections from raindrops, are identified on the map. The signals of rain-cells are replaced by thermal noise signals, thus reducing the false alarms associated with the rain signal.

SUMMARY OF THE DISCLOSED TECHNIQUE

In accordance with one aspect of the disclosed technique, there is thus provided a method for object detection in a rain environment with a W-band radar detection system. The method includes the procedures of obtaining radar data of a region of interest with the W-band radar detection system, and generating a range-velocity map from the radar data. The method further includes the procedures of calculating initial threshold values in the range-velocity map using a constant false alarm rate processing technique, and establishing if a rain condition is present in the region of interest based on the amount of cells in the range velocity map exceeding the initial threshold values. If a rain condition is present, the method further includes the procedures of designating rain cells and object cells in the range velocity map, the designated rain cells forming a rain cell pattern, calculating rain cell threshold values in the rain cell pattern using the constant false alarm rate processing technique, detecting a first object cluster of an object of interest within the rain cell pattern, detecting a second object cluster of the object of interest outside the rain cell pattern in the vicinity of the first object cluster, and merging the first object cluster with the second objet cluster to form a unified object pattern. The method further includes the procedure of obtaining required information associated with the object of interest.

In accordance with a further aspect of the disclosed technique, there is thus provided a W-band radar detection system for object detection in a rain environment. The W-band radar detection system includes a radar transceiver and a processor. The radar transceiver obtains radar data of a region of interest. The processor generates a range-velocity map from the radar data, calculates initial threshold values in the range-velocity map using a constant false alarm rate processing technique, and establishes if a rain condition is present in the region of interest based on the amount of cells in the range velocity map exceeding the initial threshold values. If a rain condition is present, the processor designates rain cells and object cells in the range velocity map, the designated rain cells forming a rain cell pattern, calculates rain cell threshold values in the rain cell pattern using the constant false alarm rate processing technique, detects a first object cluster of an object of interest within the rain cell pattern, detects a second object cluster of the object of interest outside the rain cell pattern in the vicinity of the first object cluster, merges the first object cluster with the second objet cluster to form a unified object pattern, and obtains required information associated with the object of interest.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosed technique will be understood and appreciated more fully from the following detailed description taken in conjunction with the drawings in which:

Figure 1 is a schematic illustration of a graph of the atmospheric attenuation of radio waves as a function of frequency, for different rain conditions;

Figure 2 is a schematic illustration of a graph of the receiver radar signal intensity in the presence of rain as a function of range;

Figure 3 is a block diagram of a radar detection system, constructed and operative in accordance with an embodiment of the disclosed technique;

Figure 4 is a schematic illustration of two graphs, the first graph depicting the transmitted frequency waveform and the received frequency waveform of the radar transceiver of Figure 3, the second graph depicting the baseband frequency waveform of the radar transceiver of Figure 3;

Figure 5 is a flow diagram of a method for object detection in a rain environment with a millimeter-wave radar detection system, operative in accordance with an embodiment of the disclosed technique;

Figure 6 is a schematic illustration of a range-velocity map showing an object cell pattern of an object of interest detected by the

radar detection system of Figure 3, in accordance with an embodiment of the disclosed technique;

Figure 7 is a schematic illustration of a range-velocity map showing a rain cell pattern of the reflection from rain as detected by the radar detection system of Figure 3, in accordance with an embodiment of the disclosed technique; and

Figure 8 is a schematic illustration of a range-velocity map showing the rain cell pattern of Figure 7 and an object cell pattern of an object of interest having a first cluster within the rain cell pattern and a second cluster outside the rain cell pattern, in accordance with an embodiment of the disclosed technique.

DETAILED DESCRIPTION OF THE EMBODIMENTS

The disclosed technique provides a method for obtaining data associated with an object of interest under rainy conditions using a millimeter-wave radar detection system, while mitigating the effect of rain clutter in the reflected radar signal. The disclosed technique is applied to a W-band, repetitive linearly frequency modulated continuous-wave (FMCW) type radar. FMCW radar facilitates processing techniques which derive simultaneously the range and velocity of the detected objects, displayed as cell patterns in two-dimensional cell arrays known as range-velocity maps. A cell pattern associated with rain is used to apply an object detection scheme that is minimally affected by the radar clutter resulting from the rain.

Reference is now made to Figure 3, which is a block diagram of a radar system, generally referenced 200, constructed and operative in accordance with an embodiment of the disclosed technique. Radar system 200 includes a radar transceiver 220 (enclosed in a dashed line), an analog to digital converter (ADC) 205 and a signal processor and radar controller 207. Radar transceiver 220 includes a radar receiver antenna 201, a mixer 202, a baseband filter and amplifier 203, a radar transmitter antenna 210, a frequency modulator 212, and a radio frequency (RF) source 214. Mixer 202 is coupled with receiver antenna 201, with RF source 214, and with baseband filter and amplifier 203. Baseband filter

and amplifier 203 is further coupled with ADC 205. ADC 205 is further coupled with signal processor and radar controller 207. Signal processor and radar controller 207 is further coupled with frequency modulator 212. Frequency modulator 212 is further coupled with RF source 214. RF source 214 is further coupled with transmitter antenna 210. Radar transceiver 220 is similar to common such radar transceivers known in the art.

RF source 214 generates radio waves (RF signals) in the W-band frequency range (75-100GHz). The RF signals are modulated by frequency modulator 212 and transmitted by transmitter antenna 210 toward a region of interest. Radar receiver antenna 200 receives the radio waves reflected back from objects located in the region of interest.

Reference is now made to Figure 4, which is a schematic illustration of two graphs, the first graph referenced 310, depicting the transmitted frequency waveform and the received frequency waveform of the radar transceiver (220) of Figure 3, the second graph, referenced 320, depicting the waveform of the baseband frequency of the radar transceiver (220) of Figure 3. Graph 310 depicts in bold lines a frequency modulated (FM) transmitted radar waveform, generally referenced 319, and depicts in dotted lines the associated received radar waveform, generally referenced 309. The received radar waveform 309 is a replication of the transmitted radar waveform 319 delayed by the travel

time of the transmitted wave to the object and back from the object to receiver antenna 201. Accordingly, received radar waveform first portion 311 is the reflected replication of transmitted radar waveform first portion 301. Received radar waveform second portion 312 is the reflected replication of transmitted radar waveform second portion 302. Similarly, received radar waveform Nth portion 313 is the reflected replication of transmitted radar waveform Nth portion 303. Thus, the time delay between each transmitted radar waveform portion and the associated received radar waveform potion equals the time required for the radar wave to propagate from the transmitter antenna 210 to the object and back to receiver antenna 201.

Center frequency 315 is the non-modulated frequency of the radar transmitter antenna 200. Preferably, a center frequency of approximately 77GHz is used in accordance with the disclosed technique. The linearly shaped transmitted radar waveform 319 implies that the radar transmission frequency changes linearly around center frequency 315. The modulated frequency range determined by FM modulator 212 and time period of the linear portion of the frequency sweep are selected to include the maximal ranges and Doppler frequencies of an object that will be detected by the radar. It should be noted that other forms of frequency modulation (FM) applied to the transmitted RF signal are also within the scope of the disclosed technique. For instance, waveforms 319 and 309

may be triangular or of any other functional shape. It is further noted that radar receiver antenna 201 and radar transmitter antenna 210 may be embodied by a single antenna in conjunction with a circulator or a coupler array (or other coupling device), which isolates between the transmitted signal and the received signal.

A replication of the transmitted radar waveform and the received radar waveform enters mixer 202 (Figure 3), which outputs the frequency difference between transmitted radar waveform 319 and received radar waveform 309. The frequency difference, known as the baseband frequency, is substantially lower than the center frequency 315. Graph 320 depicts the baseband frequency waveform, generally referenced 329, associated with transmitted radar waveform 319 and received radar waveform 309 of graph 310. Frequency 321 of baseband frequency waveform 329 is the frequency difference between transmitted waveform first portion 301 and received waveform first portion 311. Frequency 322 of baseband frequency waveform 329 is the frequency difference between transmitted waveform second portion 302 and received waveform second portion 312. Frequency 323 of baseband frequency waveform 329 is the frequency difference between transmitted waveform Nth portion 303 and received waveform Nth portion 313.

Referring back to Figure 3, the frequency output of mixer 202 (i.e., baseband frequency waveform 329) enters baseband filter and

amplifier 203, which includes a band-pass filter adaptable to the baseband frequency range. ADC 205 samples the voltage level output of baseband filter and amplifier 203 at a constant rate, and these voltage samples are received by signal processor and radar controller 207. If "M" represents the number of voltage samples per transmitted and received radio waves during a certain period, and if "N" represents the number of transmitted radio waves during that period, then the output of the radar transceiver 220 (digitized by ADC 205 and arranged by signal processor and radar controller 207) is a two-dimensional digital data array of M x N dimensions. Further radar signal processing is derived by generating a range-velocity map from the two-dimensional digital data array. The range–velocity map is commonly instrumental in analyzing detected object characteristics. The horizontal axis of the map represents velocity (range rate) and the vertical axis represents range. The map is made up of an array of cells, hence the horizontal dimension of a cell represents the velocity (range rate) resolution unit, and the vertical dimension of a cell represents the range resolution unit. The features on the range-velocity map are further analyzed to derive data associated with the detected object of interest, such as the type of object, as will be elaborated upon below.

Reference is now made to Figure 5, which is a flow diagram of a method for object detection in a rain environment with a millimeter-wave

radar detection system, operative in accordance with an embodiment of the disclosed technique. The method begins, in procedure 700, with obtaining radar data of a region of interest with a W-band radar detection system. Referring to Figure 3, radar transceiver 220 transmits W-band RF signals toward a region of interest, and receives the reflected RF signals. Radar detection system 200 extracts radar data associated with the transmitted and received RF signals, including digital samples of baseband filter and gain amplifier 203 or receiver 201 output frequency, as discussed hereinabove.

The method follows, in procedure 702, with generating a range-velocity map from the radar data. Referring to Figure 3, a range-velocity map is generated by applying a two dimensional fast Fourier transform (FFT) to a digital data array that is generated by ADC 205. An FFT is applied to the M samples of each of the array rows associated with each of the N frequency sweeps of the radar, followed by an FFT that is applied to each of the N columns of the array. This two level FFT operation is commonly used with FMCW radar systems to process the data into range-velocity information of an object. The complex number output elements of the two-dimensional FFT are converted into range-velocity absolute values by the square root of the sum of the real element squared and the imaginary element squared (absolute value of a complex number). It is possible to use alternative methods for unfolding the range-velocity data,

such as via direct algebraic calculation from two selected sweep times of the receiver output.

Reference is now made to Figure 6, which is a schematic illustration of a range-velocity map, generally referenced 550, showing an object cell pattern, referenced 500, of an object of interest detected by the radar transceiver of Figure 3 during clear weather conditions, in accordance with an embodiment of the disclosed technique. Range-velocity map 550 represents an exemplary range-velocity map generated by radar transceiver 220 during clear weather conditions (i.e., not during rainy conditions). According to map 550, the range of detected object 500 is approximately 50m and the velocity of the object varies between approximately -2m/sec to +3m/sec, which is a characteristic Doppler spread of a walking person. It is appreciated that the detected object 500 is clearly visible on map 550.

The method follows, in procedure 704, with calculating initial threshold values in the range-velocity map. This calculation is carried out by deriving range and velocity signal intensity averages of the neighboring cells of each particular cell of the range-velocity map, and then establishing for each cell an adaptive and localized threshold value by using what is known as a Constant False Alarm Rate (CFAR) detection principle. A CFAR detection principle is a data-dependent processing technique designed to identify objects in an environment with varying

background noise, by calculating the average noise level at a plurality of neighboring map cells surrounding each of the map cells and setting the detection threshold at a value of predetermined ratio to the calculated average noise. Consequently, the false alarm rate is maintained substantially fixed, while providing a high detection probability for a signal reflected from an object.

In procedure 706, it is established whether or not a rain condition is present in the region of interest, based on the amount of cells in the range-velocity map exceeding the initial threshold values. Referring to Figure 6, if the number of cells in range-velocity map 550 which have signal intensity values that exceed the respective initial threshold value is greater than a predetermined amount (e.g., or if the percentage of such cells relative to the other cells in the map exceeds a predetermined ratio value), then it is concluded that a rain condition exists.

If it is not raining (i.e., if a rain condition is determined to not exist in procedure 706), then the method follows, in procedure 708, with detecting an object of interest, using standard radar detection techniques for object detection. Subsequently, in procedure 710, any required information associated with the object of interest is obtained, such as the range, the velocity and the angle of the object. The range and velocity data can be obtained directly from the range-velocity map. The angle (i.e., the spatial angle of the object relative to the radar system) can be

obtained in several different ways. For example, a low resolution angle estimation approach based on the specific beam direction may be used. Alternatively, the received amplitudes in neighboring/partially overlapping antenna beams may be compared, or the comparison can be done over the phase of the received signal.

If it is raining (i.e., if a rain condition is determined to exist in procedure 706), then the method follows with procedure 720. In procedure 720, rain cells and object cells are designated in the range-velocity map. From all the cells in the range-velocity map having a signal intensity value above the respective initial threshold value, if the cell is adjacent or contiguous with other such cells on the map, then it is designated as a "rain cell", whereas if the cell location is discrete or separate from other such cells on the map, then it is designated as an "object cell". The collection of designated rain cells forms a contiguous "rain cell pattern". Reference is now made to Figure 7, which is a schematic illustration of a range-velocity map, referenced 650, showing a rain cell pattern, referenced 600, of the reflection from rain as detected by the radar detection system of Figure 3, in accordance with an embodiment of the disclosed technique. The designated rain-cells are depicted in Figure 7 as the darker pixels, arranged consecutively in the form of rain-cell pattern 600. Rain cell pattern 600 is characterized by a "snake like" shape, which is a pattern typical of windy or gusty weather conditions.

The range characteristic of rain cell pattern 600 extends from the minimum range to the maximum range of the radar, since rain drops are present in the entire radar depth of field. The velocity of rain cell pattern 600 varies in a substantially sinusoidal manner between approximately -2m/sec and approximately +2m/sec. The changing winds along the depth of field results in the rain cell pattern generally defining a smooth shape, such as the sinusoidal shape of rain cell pattern 600. It is appreciated that alternative rain cell patterns may also be obtained, and the rain cell pattern does not necessarily extend from the minimum to maximum range (if for example, rain is not present everywhere in the radar depth of field). Furthermore, other exemplary rain cell patterns may correspond to different velocities (i.e., beyond the range of -2m/sec to +2m/sec). The cells in map 650 which exceed the respective initial threshold value but which do not fall within rain cell pattern 650 are considered potential object cells.

In procedure 722, rain cell threshold values are calculated in the range-velocity map, using a CFAR processing technique. An updated threshold is calculated for the designated rain cells in order to detect objects located within the rain cell pattern itself. The updated threshold values are calculated from the average noise level of neighboring rain-cells of each cell in the rain-cell pattern, similar to the process described hereinabove with reference to procedure 704. The rain cell threshold

values are generally higher than the initial calculated threshold values, and are generally set at a few decibels higher than the calculated average background noise.

The rain is generally present everywhere in the region of interest, including in the vicinity of the object of interest. In addition, the object typically extends over several cells in the range-velocity map. Therefore, a section of an object (or an entire object) may appear within the rain-cell pattern portion of the range-velocity map. Accordingly, it is necessary to identify any cells belonging to potential objects of interest within the previously designated rain cell pattern. In procedure 724, a first object cluster is detected within the designated rain cell pattern. The signal intensity values within the rain cell pattern are analyzed, and a cell that exceeds the respective rain cell threshold value (established in procedure 722) is identified as being associated with an object cell. The signal intensity associated with an object cell will generally be sufficiently high to exceed even the (higher) updated rain cell threshold value, and so an object cell will likely be identified even within a rain cell pattern.

In procedure 726, a second object cluster is detected outside of the designated rain cell pattern. The signal intensity values outside the rain cell pattern are analyzed, and a cell that exceeds the initial respective threshold value (established in procedure 704) is identified as being associated with an object cell.

Reference is now made to Figure 8, which is a schematic illustration of a range-velocity map, referenced 800, showing the rain-cell pattern 801 which is equivalent to rain-cell pattern 600 of Figure 7 and a cell pattern of an object of interest 810 having a first cluster within the rain-cell pattern and a second cluster outside the rain-cell pattern, in accordance with an embodiment of the disclosed technique. Object 810 consists of a first cluster 812 (depicted by a dashed line) and a second cluster 811 (depicted by a solid line). First object cluster 812 is located and detected within rain-cell pattern 801 and second object cluster 811 is located and detected outside rain-cell pattern 801.

In procedure 728, the first object of interest cluster (detected in procedure 724) and the second object of interest cluster (detected in procedure 726) are merged to form a unified object pattern, using an object cell merging algorithm. For example, edge cells belonging to one cluster of the object of interest are repositioned adjacent to the corresponding edge cells of another cluster of the object of interest. Referring to Figure 8, first object cluster 812 and second object cluster 811 are merged, to provide the full object cell pattern of the entire object of interest 810. It is further noted that the merging algorithm eliminates "ghost targets" (i.e., when the same object cell is identified twice) and ensures an accurate calculation of the unified object parameters (range, velocity and angle). For example, if there exists a single object in the

scene, then the same object cell could potentially be detected twice in neighboring cells: once during the initial application of the CFAR processing of the range-velocity map (procedure 704) at a first cell coordinates (e.g., X,Y), and then a second time during the application of the CFAR processing of the rain cell pattern (procedure 722) at a slightly displaced location (e.g., X+1,Y). In such a case, the same object cell would be mistakenly considered as belonging to two separate objects with two distinct sets of object parameters. Accordingly, the merging algorithm identifies such a scenario and outputs the associated object cell at a single location (e.g., at cell coordinates X+0.5, Y), ensuring correct detection of a single unified object.

The method resumes with procedure 710, in which required information associated with the object of interest is obtained (as discussed previously).

It will be appreciated by persons skilled in the art that the disclosed technique is not limited to what has been particularly shown and described hereinabove.

CLAIMS

1. A method for object detection in a rain environment with a W-band radar detection system, the method comprising the procedures of:

obtaining radar data of a region of interest with said W-band radar detection system;

generating a range-velocity map from said radar data;

calculating initial threshold values in said range-velocity map using a constant false alarm rate (CFAR) processing technique;

establishing if a rain condition is present in said region of interest, based on the amount of cells in said range-velocity map exceeding said initial threshold values;

if a rain condition is present:

designating rain cells and object cells in said range-velocity map, said designated rain cells forming a rain cell pattern;

calculating rain cell threshold values in said rain cell pattern using said CFAR processing technique;

detecting a first object cluster of an object of interest within said rain-cell pattern;

detecting a second object cluster of said object of interest outside said rain cell pattern in the vicinity of said first object cluster;

merging said first object cluster with said second object cluster to form a unified object pattern;

and

obtaining required information associated with said object of interest.

2. The method according to claim 1, wherein said range-velocity map is obtained by applying a first fast Fourier transform (FFT) to each of the rows of a two-dimensional sampled data matrix associated with said radar data, applying a second FFT to the columns of said data matrix, and calculating absolute values of the complex number elements of said data matrix.

3. The method according claim 1, wherein said initial threshold values are determined as a function of the average thermal noise level of the radar signal of said W-band radar detection system.

4. The method according to claim 1, wherein said procedure of establishing if a rain condition is present comprises counting the number of cells which exceed the respective said initial threshold value, and verifying that said number of cells is above a predetermined threshold number.

5. The method according to claim 1, wherein said rain cell threshold values are determined as a function of the average signal level of neighbouring rain cells within said rain cell pattern.

6. The method according to claim 1, wherein said required information associated with said object of interest comprises at least one of:

the range of said object of interest;

the velocity of said object of interest; and

the angle of said object of interest.

7. The method according to claim 1, wherein said rain cells are substantially contiguous in said range-velocity map, and said object cells are substantially discrete in said range-velocity map.

8. The method according to claim 1, wherein said rain cell pattern defines a substantially smooth shape.

9. The method according to claim 1, wherein said rain cell pattern defines a snake-like shape.

10. The method according to claim 1, wherein said rain condition comprises a weather condition selected from the list consisting of:

drizzle;

light rain;

heavy rain;

downpour;

thunderstorm;

snow;

hail;

sleet; and

any combination of the above.

11. The method according to claim 1, wherein said W-band radar detection system operates at a frequency of approximately 77 GHz.

12. A W-band radar detection system for object detection in a rain environment, the system comprising:

a radar transceiver, operative to obtain radar data of a region of interest; and

a processor, coupled with said radar transceiver, operative to generate a range-velocity map from said radar data, to calculate initial threshold values in said range-velocity map using a constant

false alarm rate (CFAR) processing technique, and to establish if a rain condition is present in said region of interest, based on the amount of cells in said range-velocity map exceeding said initial threshold values,

wherein if a rain condition is present, said processor designates rain cells and object cells in said range-velocity map, said designated rain cells forming a rain cell pattern, calculates rain cell threshold values in said rain cell pattern using said CFAR processing technique, detects a first object cluster of an object of interest within said rain-cell pattern, detects a second object cluster of said object of interest outside said rain-cell pattern in the vicinity of said first object cluster, merges said first object cluster with said second object cluster to form a unified object pattern, and obtains required information associated with said object of interest.

13. The radar detection system according to claim 12, wherein said radar transceiver comprises:

a radio frequency (RF) source, operative to generate RF signals in the W-band frequency range;

a frequency modulator, operative to modulate said RF signals;

a radar transmitter antenna, operative to transmit the modulated RF signals toward said region of interest; and

a radar receiver antenna, operative to receive reflected waves of said transmitted signals.

14. The radar detection system according to claim 13, wherein said radar transmitter antenna and said radar receiver antenna comprises a single antenna and a coupling device, operative to isolate between said transmitted signals and said received signals.

15. The radar detection system according to claim 13, wherein said radar transceiver further comprises a mixer, operative to provide a baseband frequency waveform comprising the frequency difference between the waveform of said transmitted signals and the waveform of said received signals.

16. The radar detection system according to claim 15, wherein said radar transceiver further comprises a baseband filter and amplifier, operative to filter and amplify said baseband frequency waveform.

17. The radar detection system according to claim 16, further comprising an analog to digital converter (ADC), coupled with said radar transceiver and said processor, said ADC operative to sample said filtered and amplified baseband frequency.

18. The radar detection system according to claim 12, operative at a frequency of approximately 77 GHz.

5

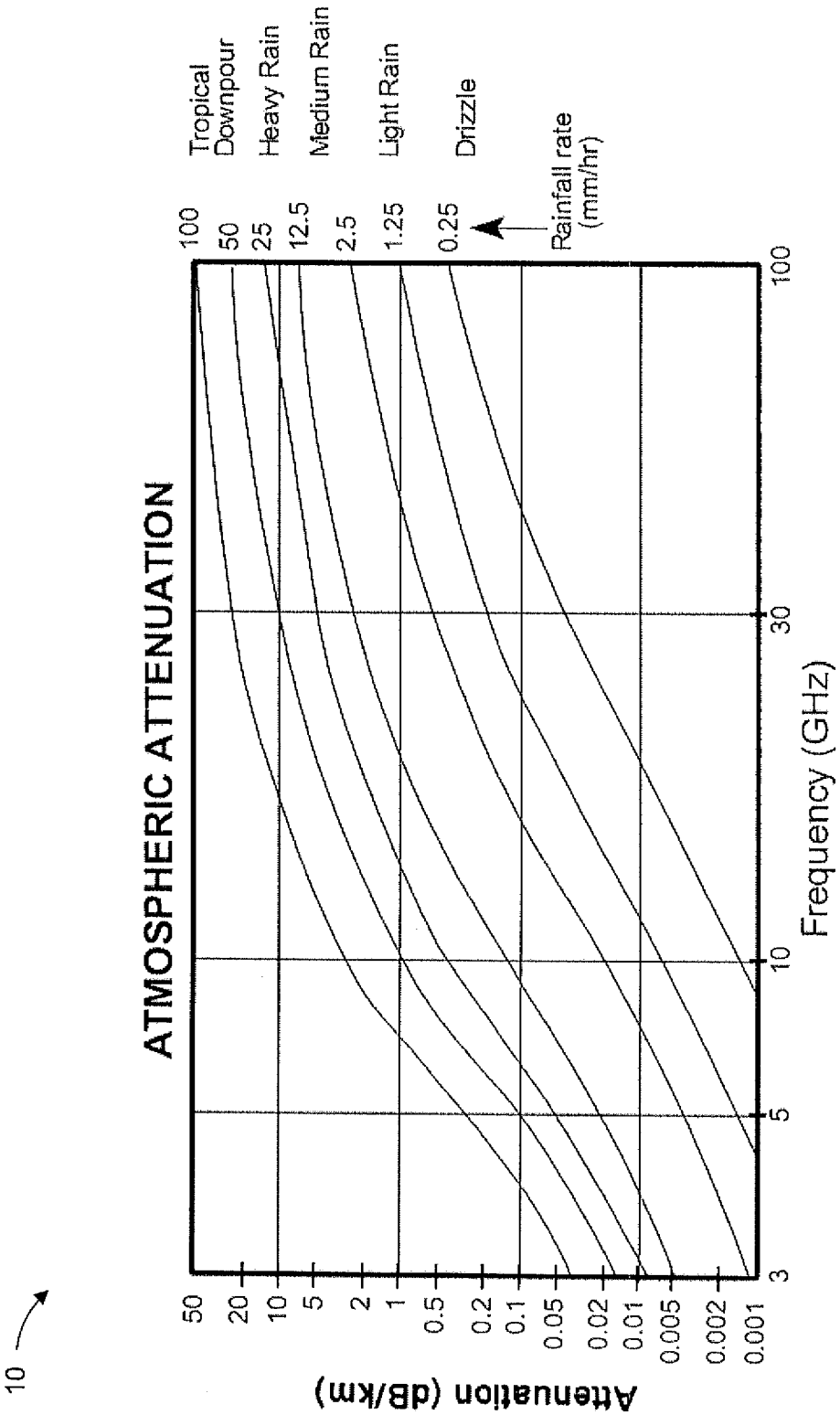

10
ATMOSPHERIC ATTENUATION
Attenuation (dB/km)
50
20
10
5
2
1
0.5
0.2
0.1
0.05
0.02
0.01
0.005
0.002
0.001
3
5
10
30
100
Frequency (GHz)
Rainfall rate (mm/hr)
100
50
25
12.5
2.5
1.25
0.25
Tropical Downpour
Heavy Rain
Medium Rain
Light Rain
Drizzle

FIG. 1

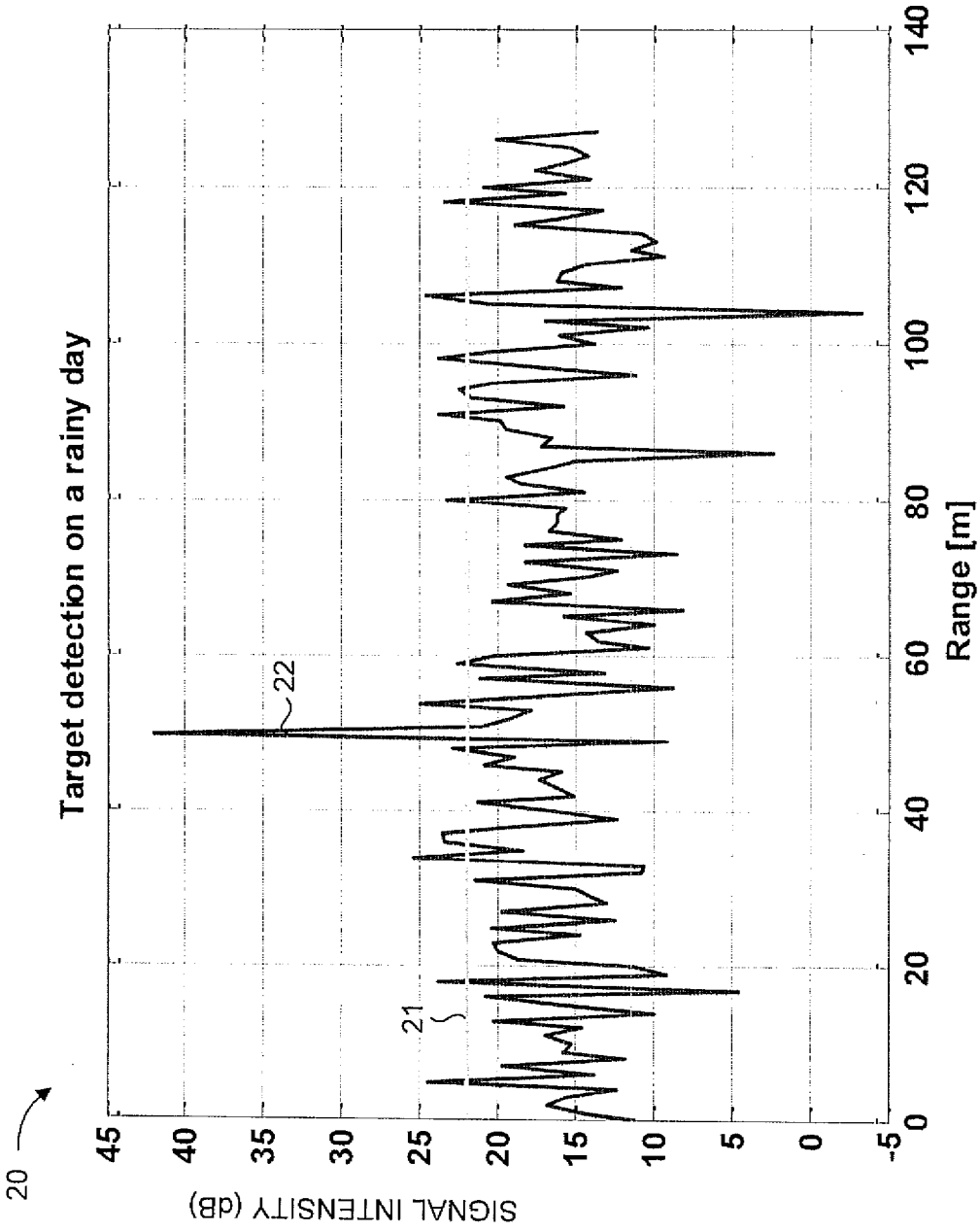

20
Target detection on a rainy day
SIGNAL INTENSITY (dB)
Range [m]
21
22
45
40
35
30
25
20
15
10
5
0
-5
0
20
40
60
80
100
120
140

FIG. 2

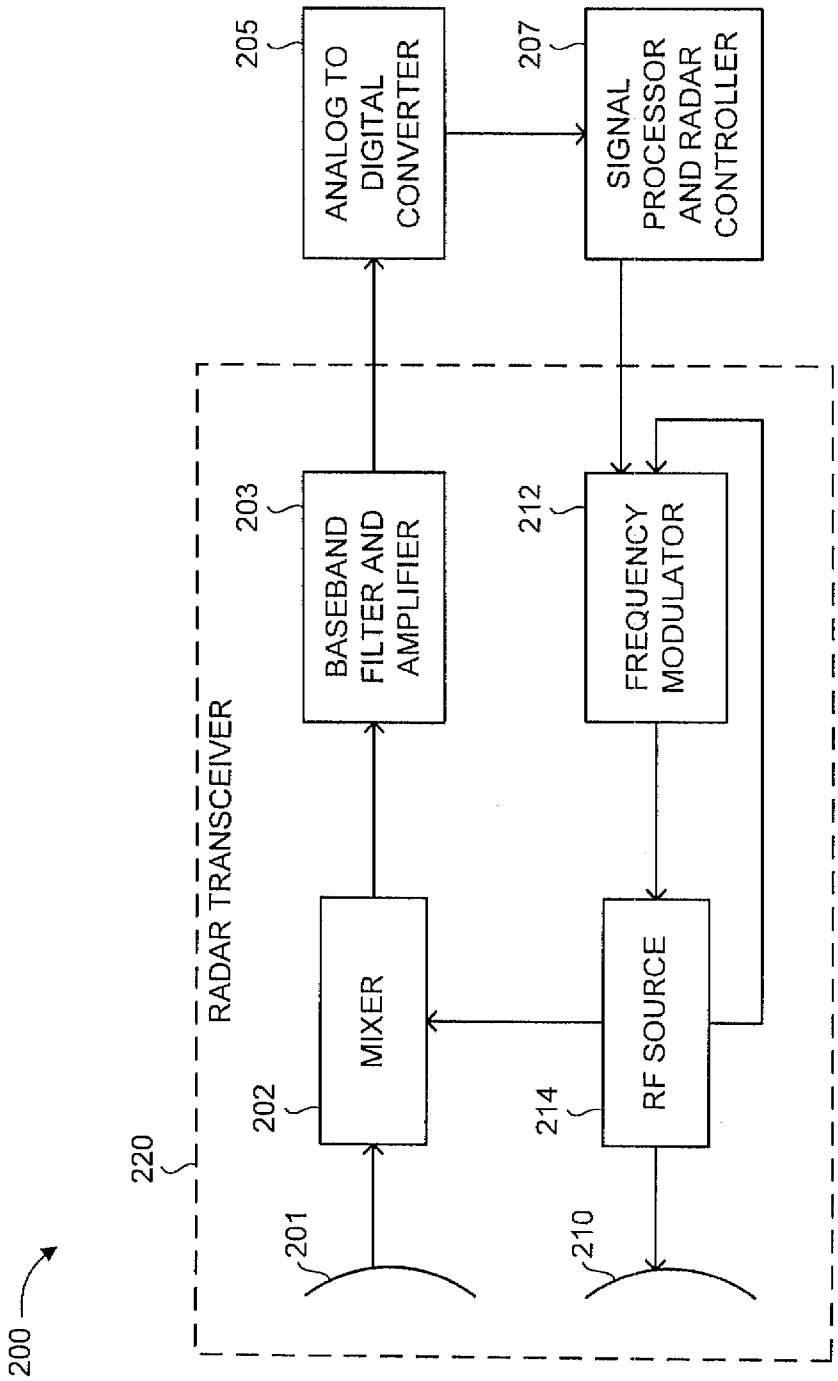

200
220
RADAR TRANSCEIVER
201
202
MIXER
203
BASEBAND FILTER AND AMPLIFIER
205
ANALOG TO DIGITAL CONVERTER
207
SIGNAL PROCESSOR AND RADAR CONTROLLER
210
214
RF SOURCE
212
FREQUENCY MODULATOR

FIG. 3

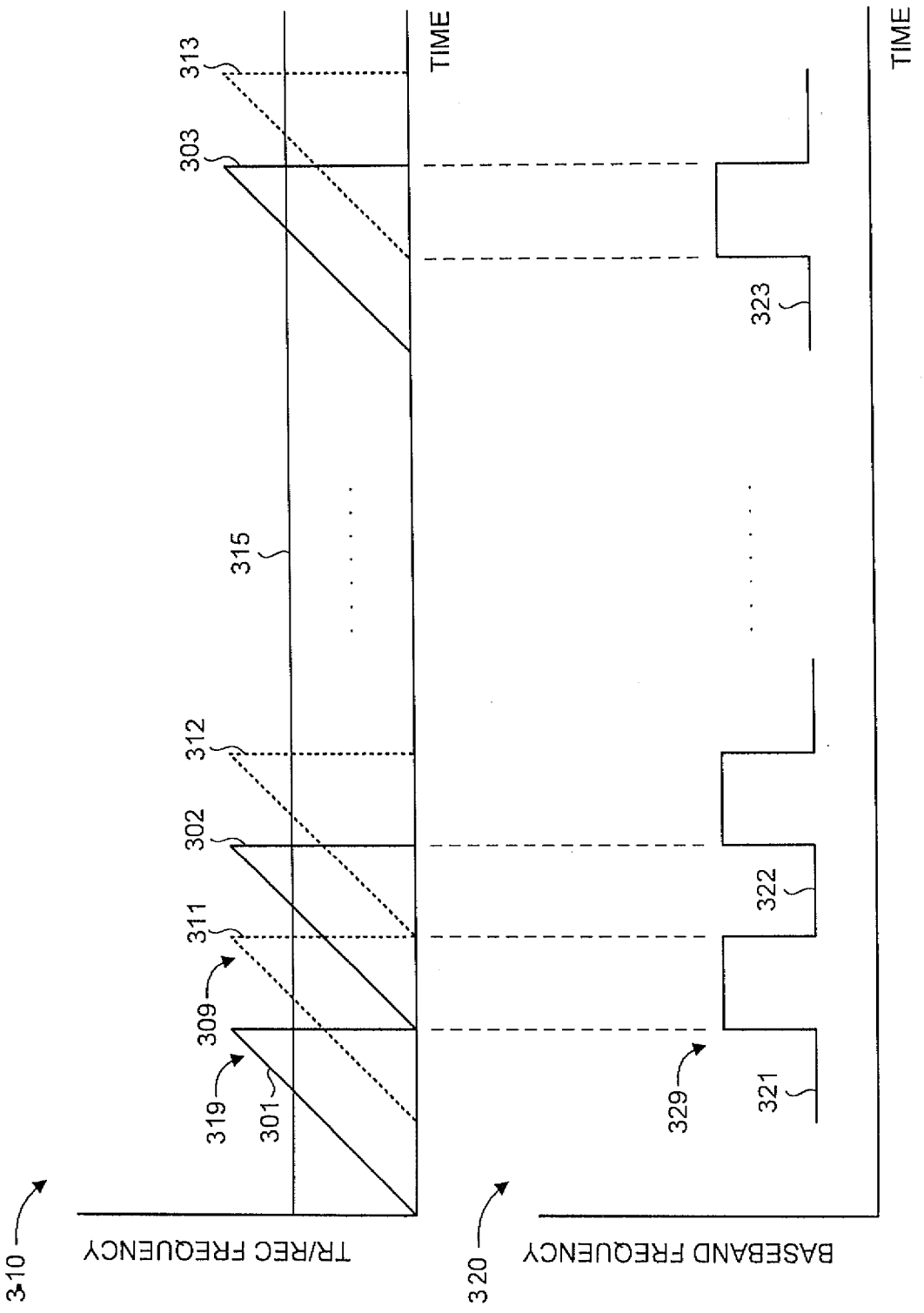

310
TR/REC FREQUENCY
TIME
313
303
315
312
302
311
309
319
301
320
BASEBAND FREQUENCY
TIME
323
322
321
329

FIG. 4

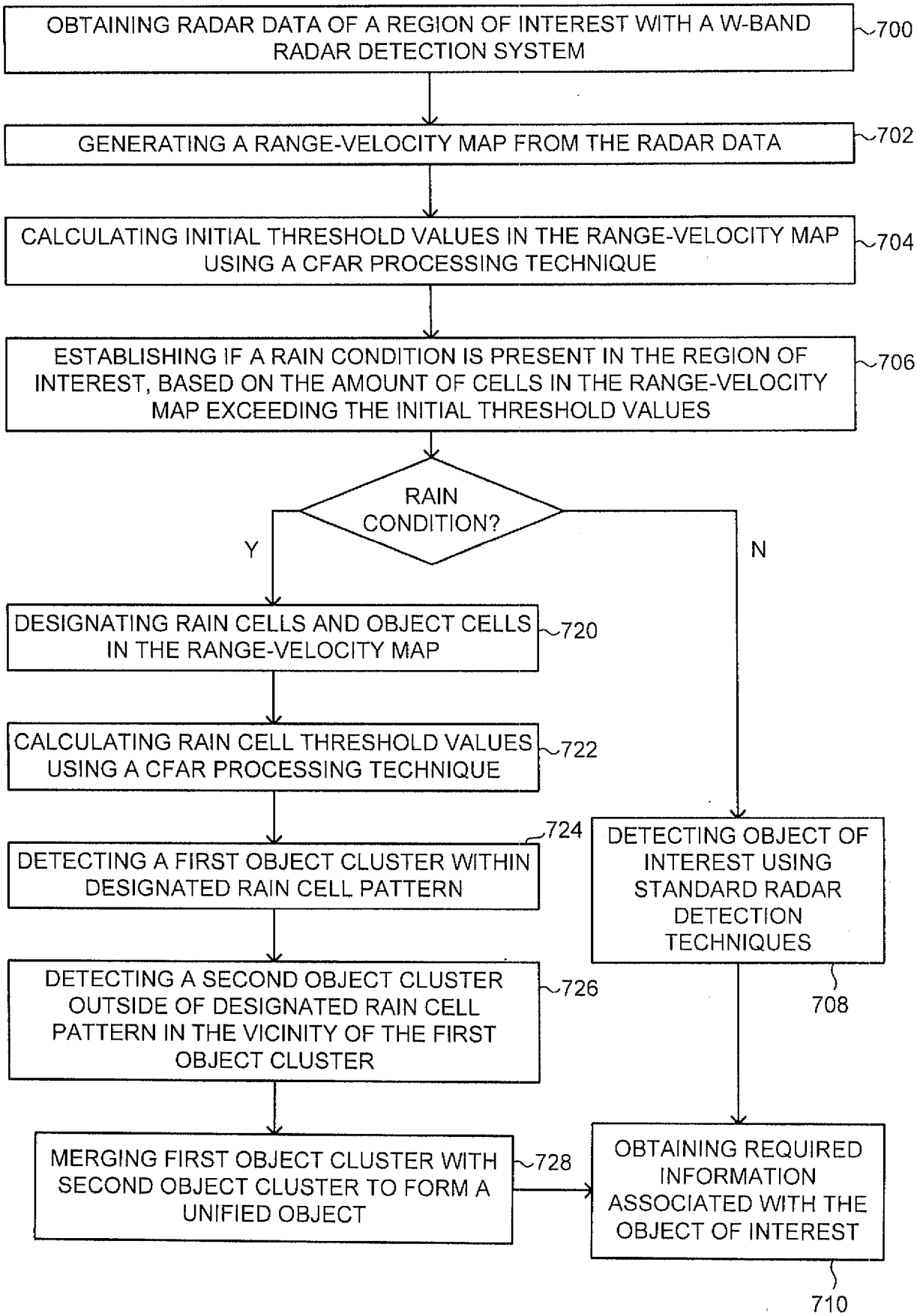

OBTAINING RADAR DATA OF A REGION OF INTEREST WITH A W-BAND RADAR DETECTION SYSTEM
700
GENERATING A RANGE-VELOCITY MAP FROM THE RADAR DATA
702
CALCULATING INITIAL THRESHOLD VALUES IN THE RANGE-VELOCITY MAP USING A CFAR PROCESSING TECHNIQUE
704
ESTABLISHING IF A RAIN CONDITION IS PRESENT IN THE REGION OF INTEREST, BASED ON THE AMOUNT OF CELLS IN THE RANGE-VELOCITY MAP EXCEEDING THE INITIAL THRESHOLD VALUES
706
RAIN CONDITION?
Y
N
DESIGNATING RAIN CELLS AND OBJECT CELLS IN THE RANGE-VELOCITY MAP
720
CALCULATING RAIN CELL THRESHOLD VALUES USING A CFAR PROCESSING TECHNIQUE
722
724
DETECTING A FIRST OBJECT CLUSTER WITHIN DESIGNATED RAIN CELL PATTERN
DETECTING OBJECT OF INTEREST USING STANDARD RADAR DETECTION TECHNIQUES
DETECTING A SECOND OBJECT CLUSTER OUTSIDE OF DESIGNATED RAIN CELL PATTERN IN THE VICINITY OF THE FIRST OBJECT CLUSTER
726
708
MERGING FIRST OBJECT CLUSTER WITH SECOND OBJECT CLUSTER TO FORM A UNIFIED OBJECT
728
OBTAINING REQUIRED INFORMATION ASSOCIATED WITH THE OBJECT OF INTEREST
710

FIG. 5

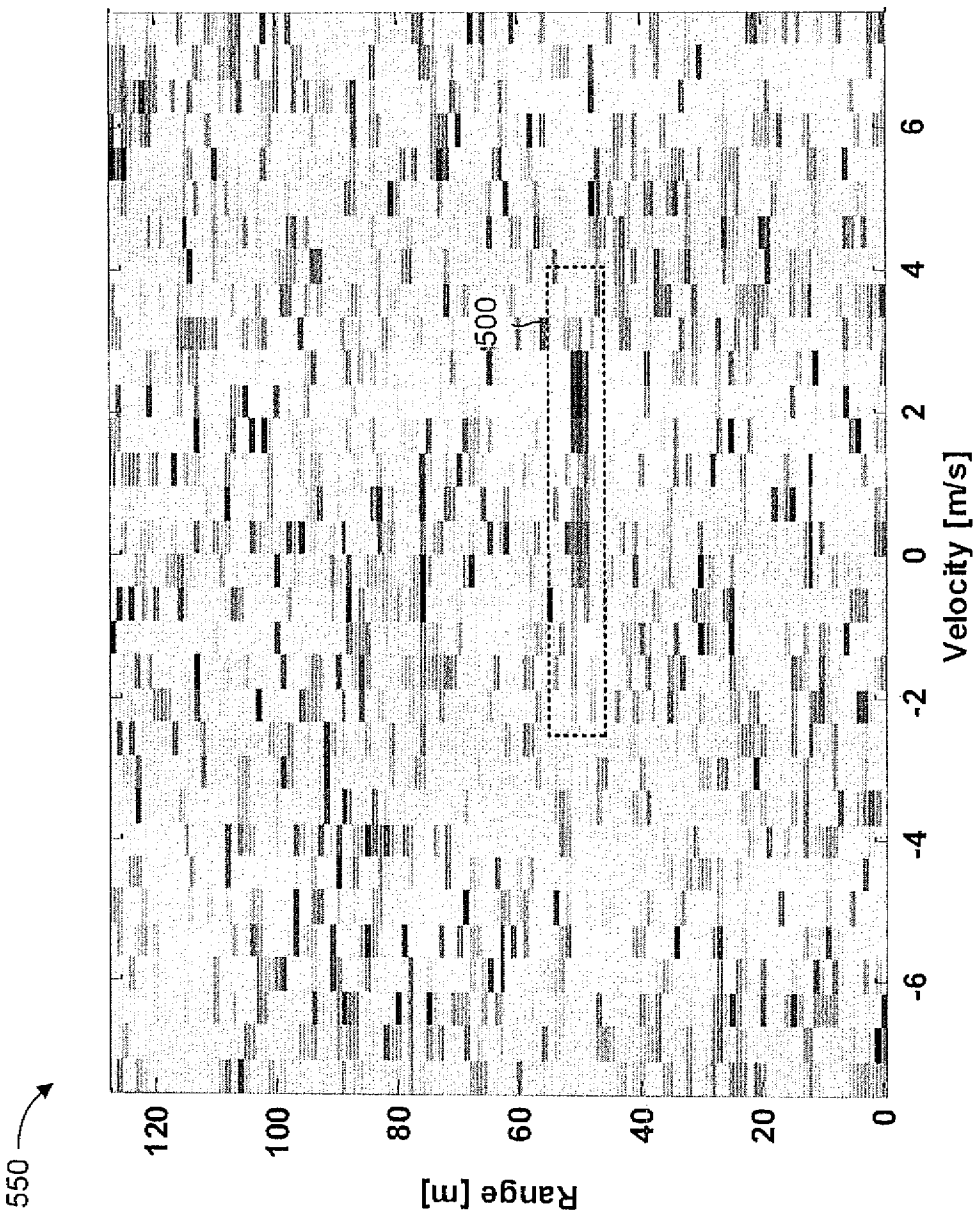


FIG. 6

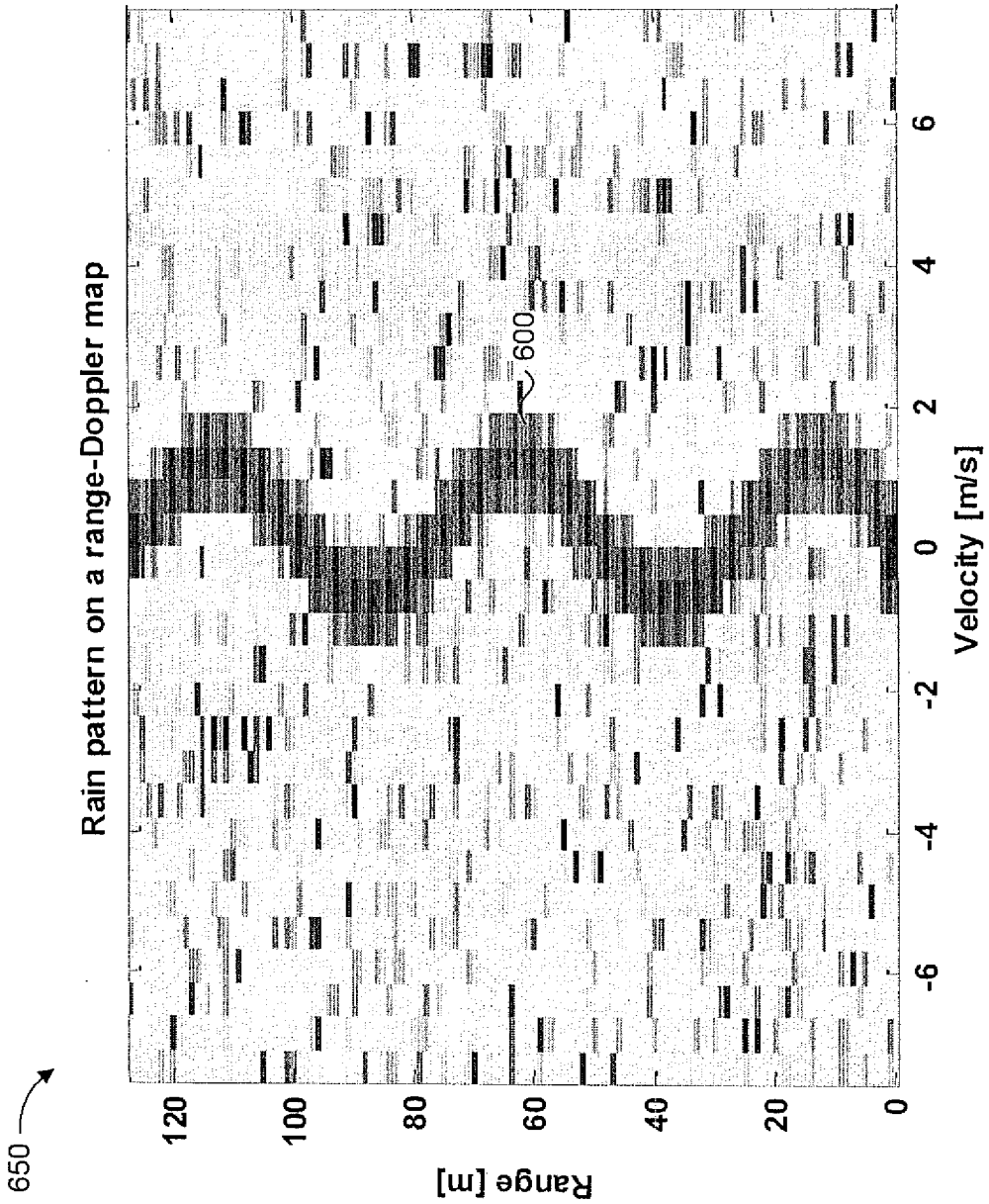

650
Rain pattern on a range-Doppler map
600
Range [m]
120
100
80
60
40
20
0
Velocity [m/s]
-6
-4
-2
0
2
4
6

FIG. 7

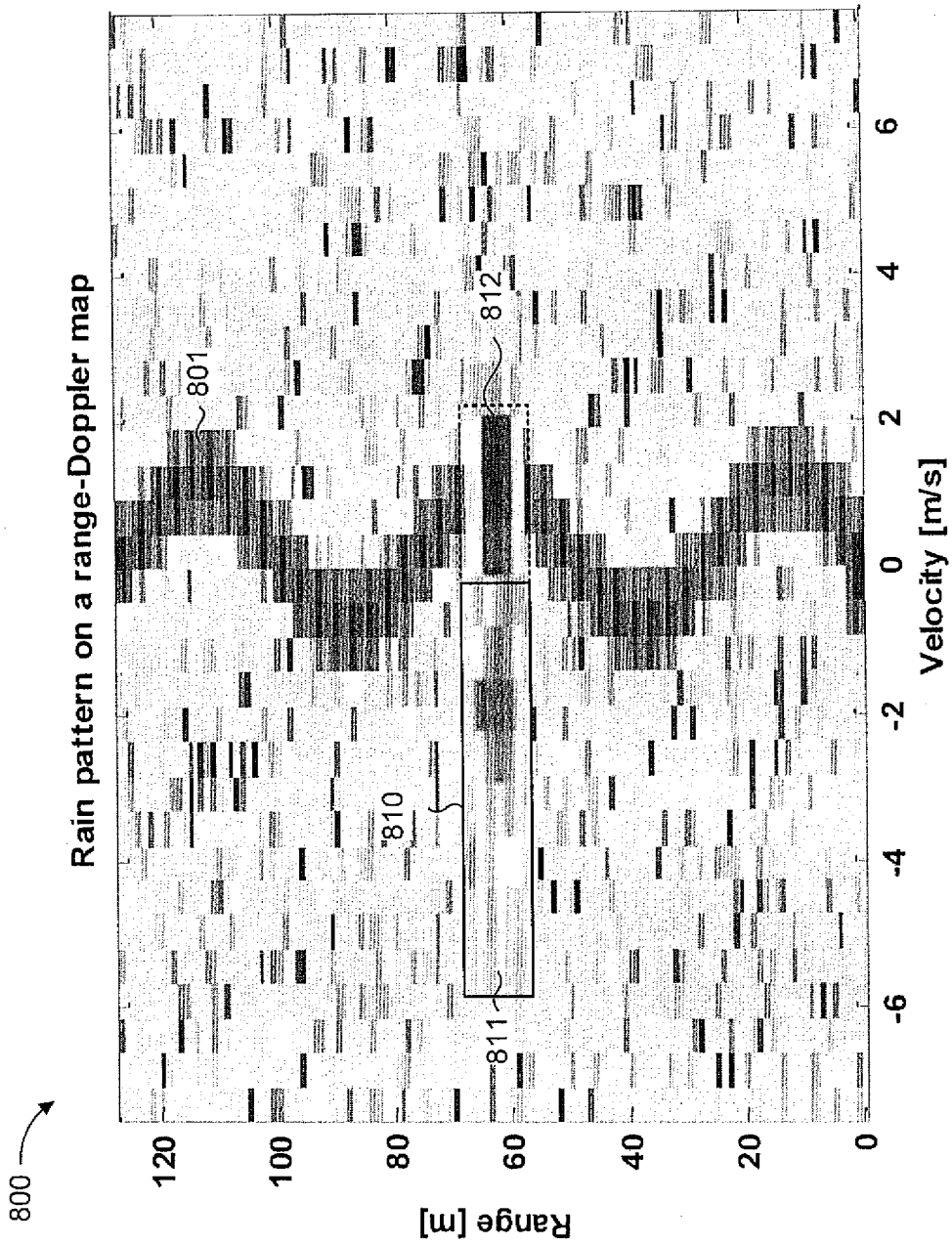

800
Rain pattern on a range-Doppler map
Range [m]
120
100
80
60
40
20
0
Velocity [m/s]
6
4
2
0
-2
-4
-6
801
810
811
812

FIG. 8

INTERNATIONAL SEARCH REPORT

International application No.
PCT/IL2013/050039

A. CLASSIFICATION OF SUBJECT MATTER

IPC (2013.01) G01S 13/00, G01S 13/06, G01S 13/52, G01S 13/42

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)

IPC (2013.01) 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)

Databases consulted: THOMSON INNOVATION, Esp@cenet, Google Patents, Google Scholar, FamPat database
Search terms used: RADAR RAIN FALSE ALARM RATE RANGE VELOCITY SPEED DISTANCE DOPPLER THRESHOLD CLUTTER

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 2005285773 A1 HARTZSTEIN et al. 29 Dec 2005 (2005/12/29) The whole document	1-18
A	US 2006238412 A1 BLUNT et al. 26 Oct 2006 (2006/10/26) The whole document	1-18
A	US 4137532 A TAYLOR, JR. et al. 30 Jan 1979 (1979/01/30) The entire document, especially column 1, lines 51-65; column 2, lines 18-31;column 3, lines 7-19; column 4, line 66-column 5, line2; column 13, lines 52-64	1-18
A	US 5374932 A WYSCHOGROD et al. 20 Dec 1994 (1994/12/20) The entire document, especially column 18, line 56 - column 23, line 9; column 73, lines 25-49	1-18

☐ 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
09 May 2013	13 May 2013
Name and mailing address of the ISA: Israel Patent Office Technology Park, Bldg.5, Malcha, Jerusalem, 9695101, Israel Facsimile No. 972-2-5651616	Authorized officer PLACHINTA Ekaterina Telephone No. 972-2-5651740

INTERNATIONAL SEARCH REPORT
Information on patent family members

International application No.
PCT/IL2013/050039

Patent document cited search report	Publication date	Patent family member(s)	Publication Date
US 2005285773 A1	29 Dec 2005	AU 2003231900 A1	22 Dec 2003
		AU 2003231900 A8	22 Dec 2003
		EP 1532462 A2	25 May 2005
		EP 1532462 A4	21 Dec 2005
		US 2005285773 A1	29 Dec 2005
		US 7420502 B2	02 Sep 2008
		WO 03104833 A2	18 Dec 2003
		WO 03104833 A3	13 May 2004
US 2006238412 A1	26 Oct 2006	US 2006238412 A1	26 Oct 2006
		US 7286079 B2	23 Oct 2007
US 4137532 A	30 Jan 1979	US 4137532 A	30 Jan 1979
US 5374932 A	20 Dec 1994	US 5374932 A	20 Dec 1994