US010404261B1

(12) **United States Patent**
Josefsberg et al.

(10) **Patent No.: US 10,404,261 B1**
(45) **Date of Patent: Sep. 3, 2019**

(54) **RADAR TARGET DETECTION SYSTEM FOR AUTONOMOUS VEHICLES WITH ULTRA LOW PHASE NOISE FREQUENCY SYNTHESIZER**

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(72) Inventors: **Yekutiel Josefsberg**, Netanya (IL); **Tal Lavian**, Sunnyvale, CA (US); **Eran Dor**, Sunnyvale, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 0 days.

(21) Appl. No.: **16/221,522**

(22) Filed: **Dec. 16, 2018**

Related U.S. Application Data

(63) Continuation-in-part of application No. 15/995,557, filed on Jun. 1, 2018, now Pat. No. 10,205,457.

(51) **Int. Cl.**

H03L 7/08	(2006.01)
G01S 13/93	(2006.01)
H03L 7/087	(2006.01)
H03L 7/091	(2006.01)

(52) **U.S. Cl.**
CPC ***H03L 7/087*** (2013.01); ***G01S 13/931*** (2013.01); ***H03L 7/08*** (2013.01); ***H03L 7/091*** (2013.01)

(58) **Field of Classification Search**
CPC H03L 7/00; H03L 7/06; H03L 7/07; H03L 7/08; H03L 7/083; H03L 7/085; H03L 7/087; H03L 7/091; G01S 13/931
See application file for complete search history.

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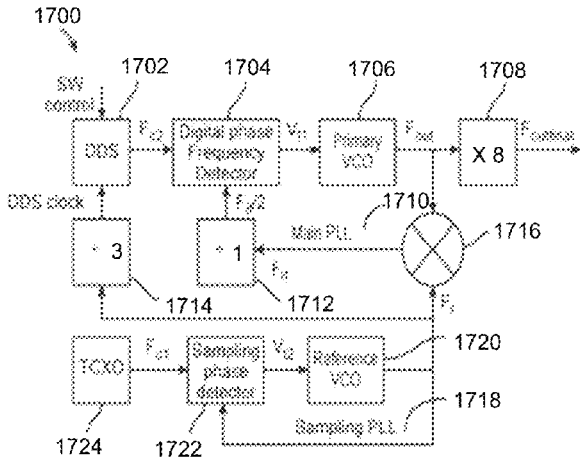
(Continued)

Primary Examiner — Peter M Bythrow

(57) **ABSTRACT**

A system for detecting the surrounding environment of vehicle comprising a RADAR unit and at least one ultra-lowphase-noise frequency synthesizer, is provided. A RADAR unit configured for detecting the presence and characteristics of one or more objects in various directions. The RADAR unit may include a transmitter for transmitting at least one radio signal, and a receiver for receiving the at least one radio signalreturned from the one or more objects. The ultra-lowphase-noisefrequency synthesizer may utilize a dual loop design comprising one main PLL and one sampling PLL, where the main PLL might include a DDS or Fractional-N PLL plus a variable divider, or the synthesizer may utilize a sampling PLL only, to reduce phase-noise from the returned radio signal. This system enhances the detection of the exact location of the vehicle based on the received RADAR signatures of objects, azimuth and distance.

20 Claims, 44 Drawing Sheets



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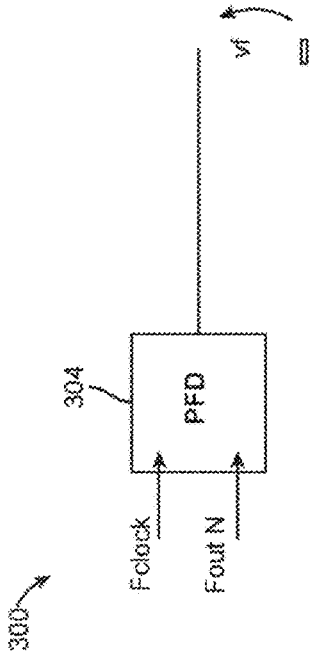


FIG. 3

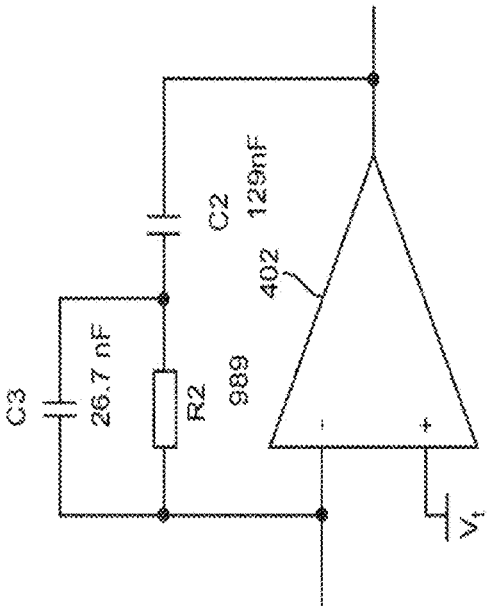


FIG. 4

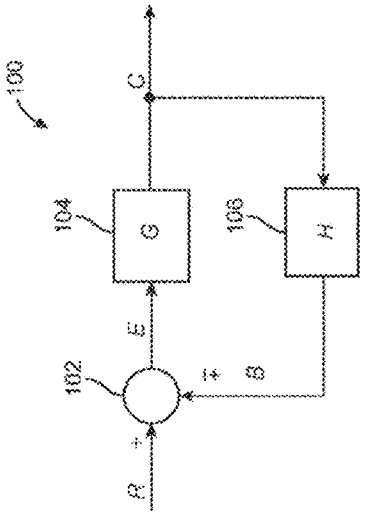


FIG. 1

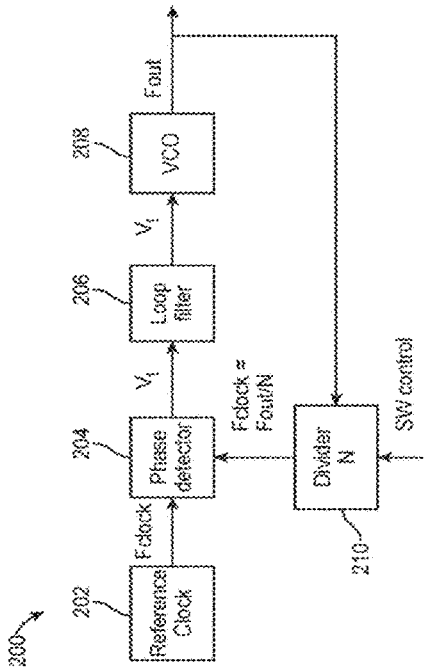


FIG. 2

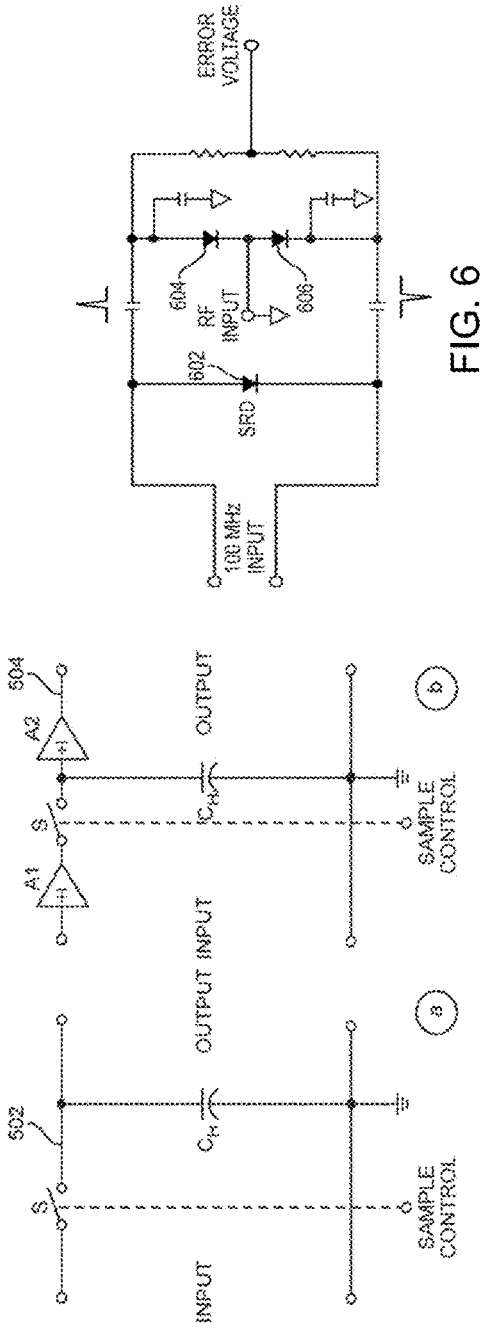
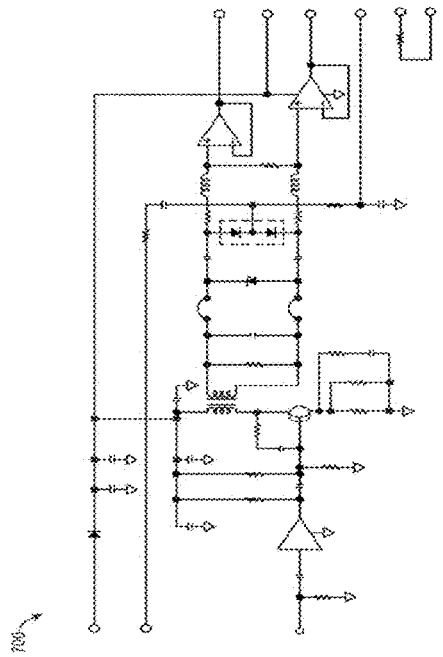


FIG. 6

FIG. 5



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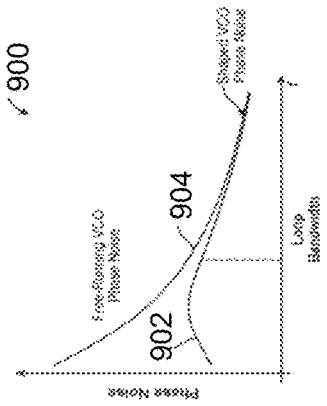
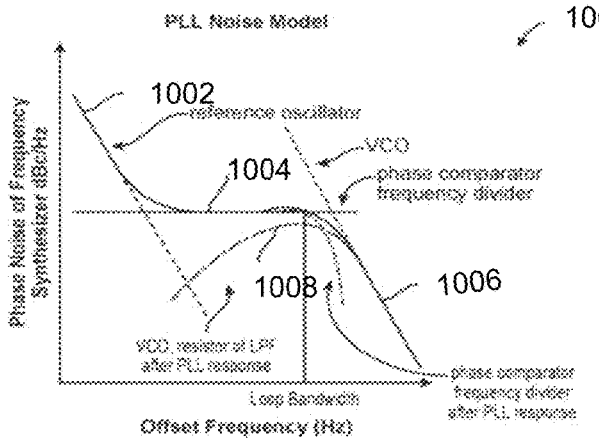
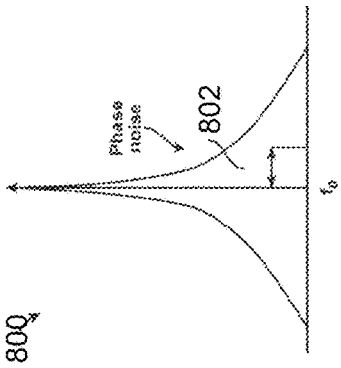


FIG. 9





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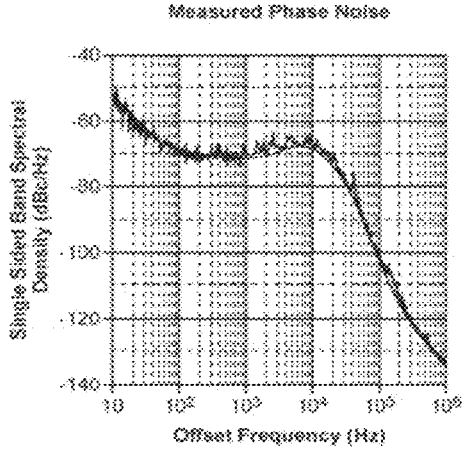
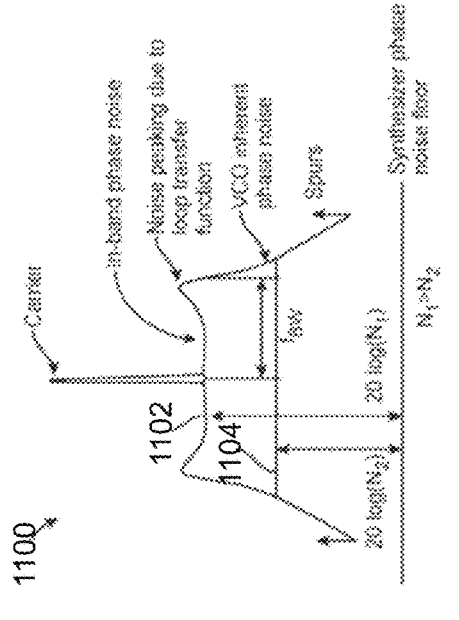


FIG. 10



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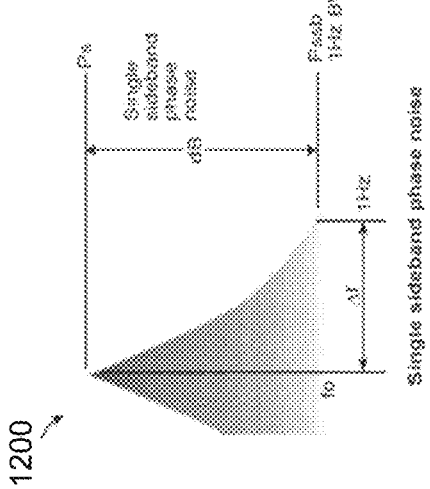


FIG. 12

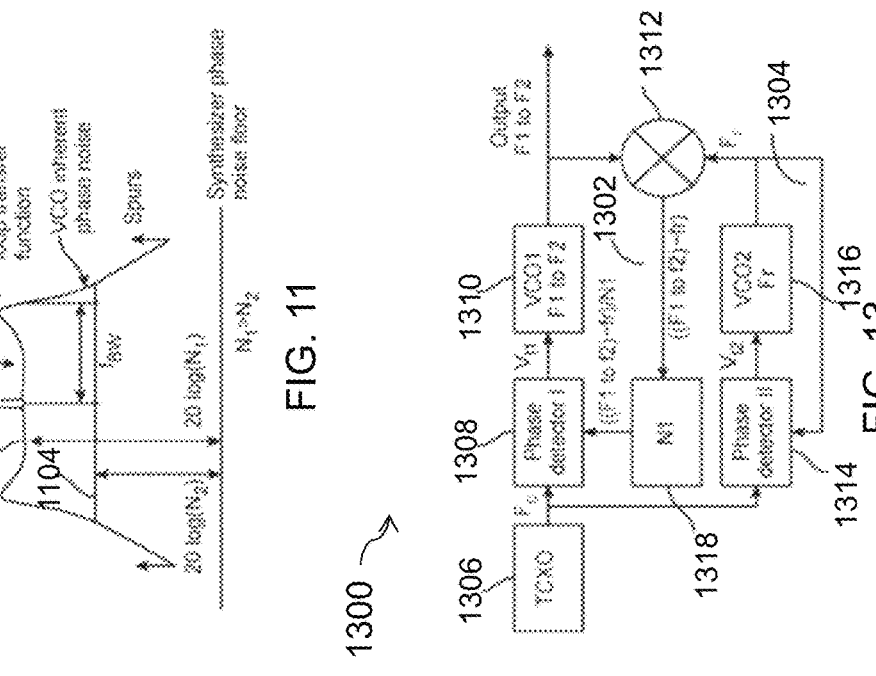


FIG. 13

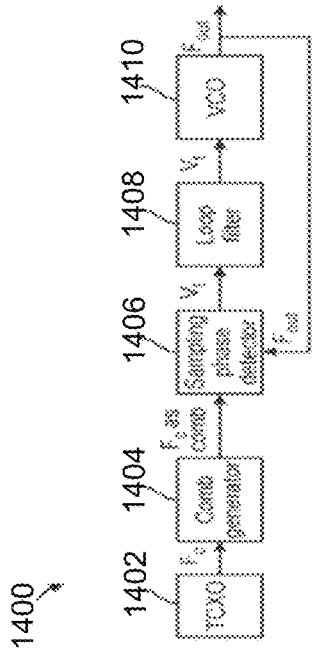
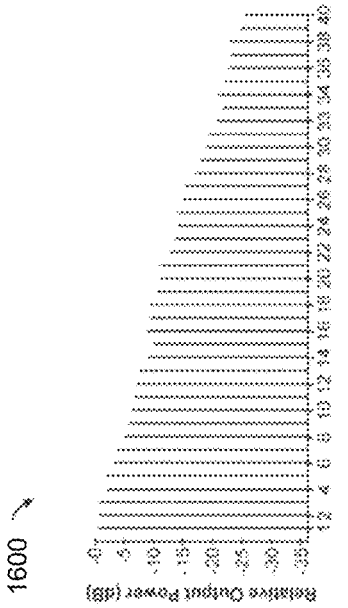


FIG. 14



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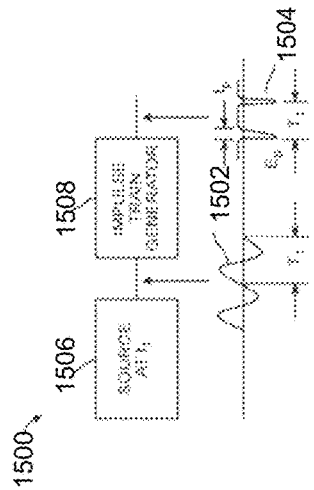

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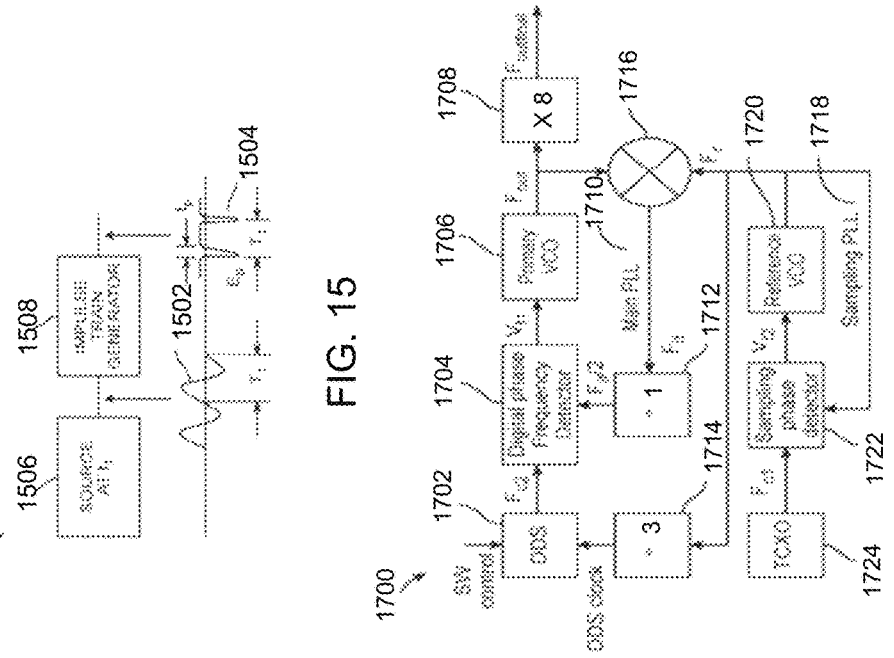

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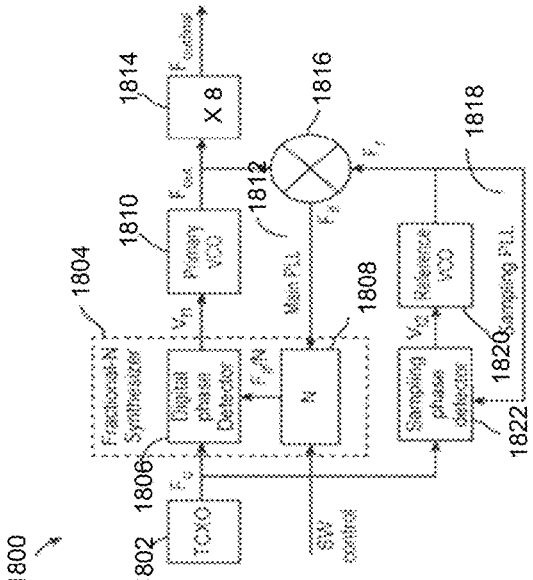

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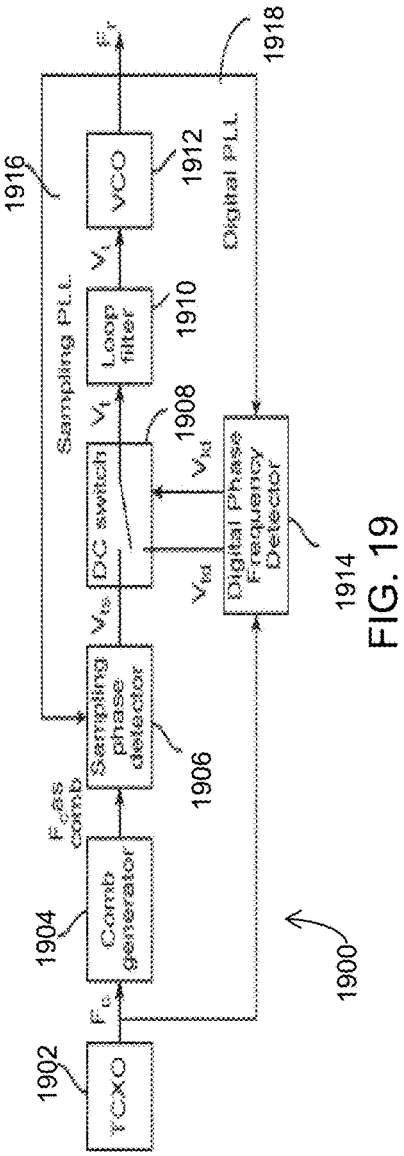

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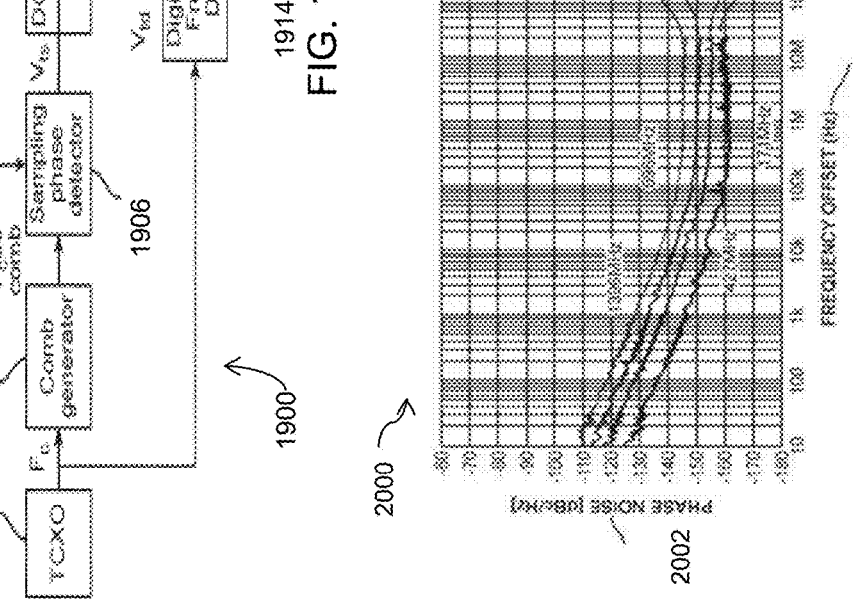

FIG. 20

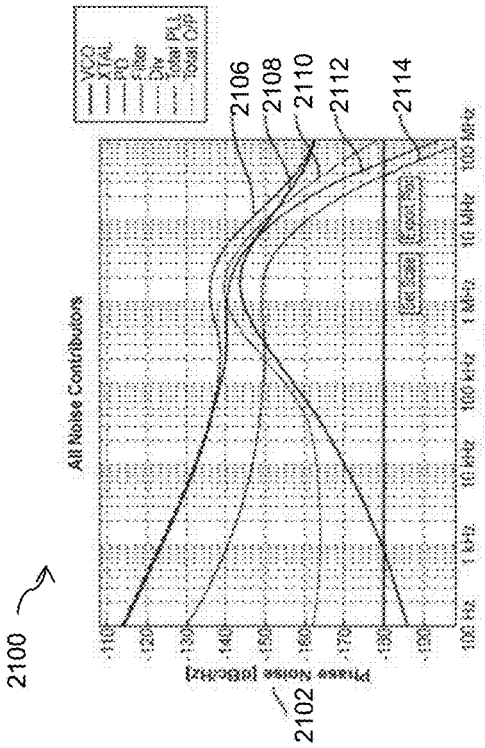

FIG. 21

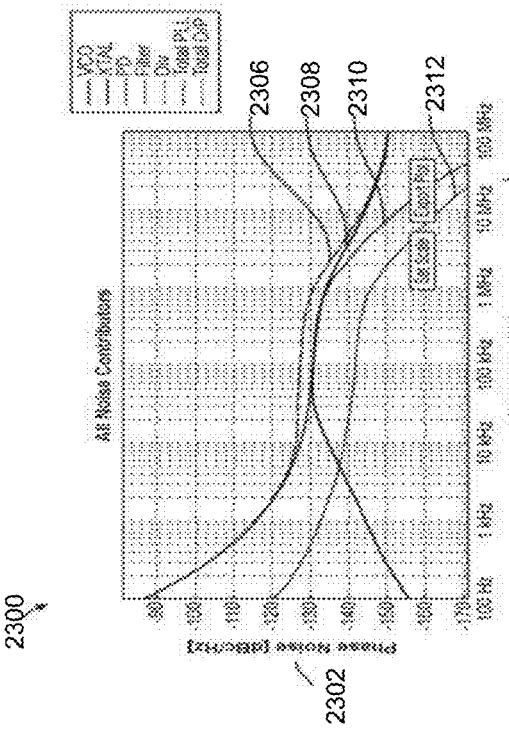

FIG. 23

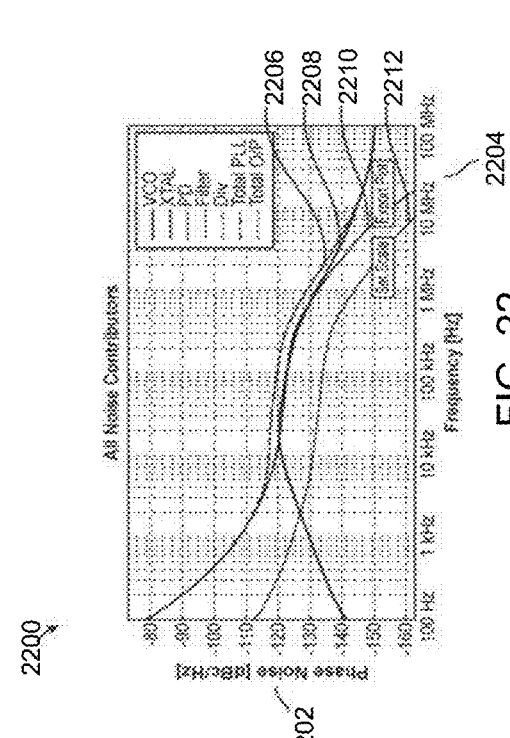

FIG. 22

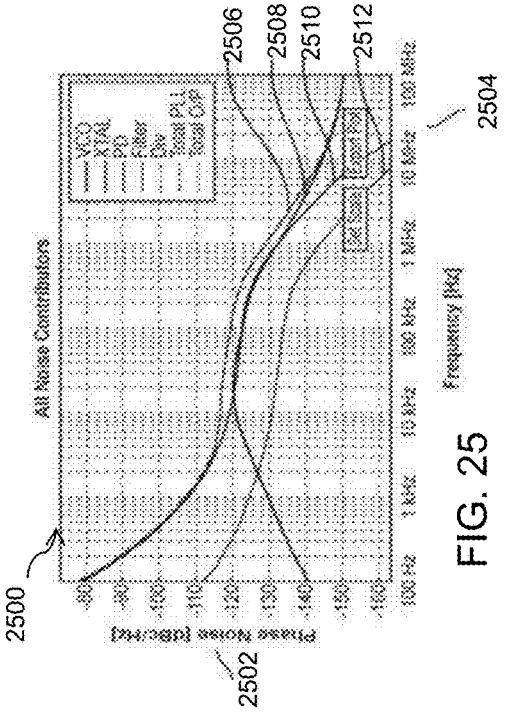

FIG. 25

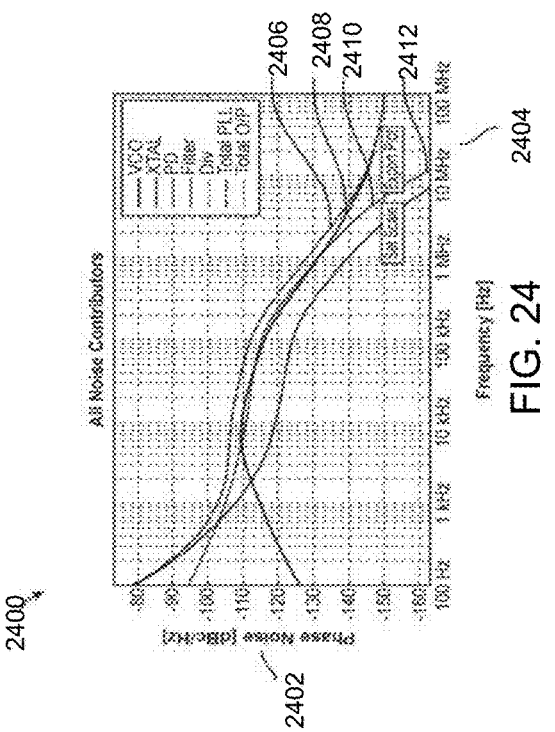

FIG. 24

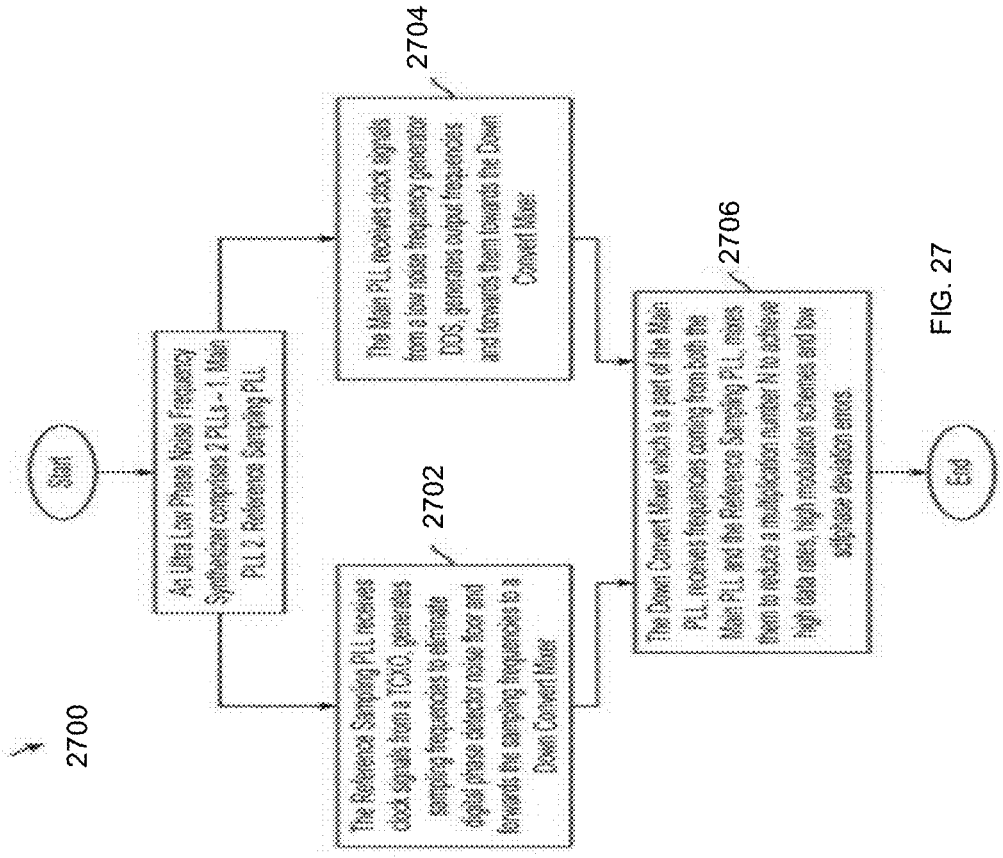
2700
Start
An Ultra Low Phase Noise Frequency Synthesizer comprises 2 PLLs – 1 Main PLL 2 Reference Sampling PLL
2702
The Reference Sampling PLL receives clock signals from a TCXO, generates sampling frequencies to eliminate digital phase detector noise floor and forwards the sampling frequencies to a Down Convert Mixer
2704
The Main PLL receives clock signals from a low noise frequency generator DDS, generates output frequencies and forwards them towards the Down Convert Mixer
2706
The Down Convert Mixer which is a part of the Main PLL, receives frequencies coming from both the Main PLL and the Reference Sampling PLL, mixes them to reduce a multiplication number N to achieve high data rates, high modulation schemes and low adiphase deviation errors
End

FIG. 27

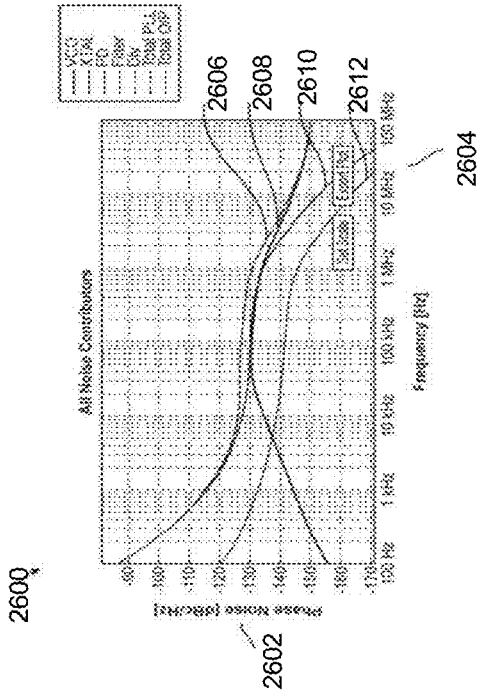
2600
2602
2604
2606
2608
2610
2612
All Noise Contributors
Phase Noise [dBc/Hz]
Frequency [Hz]
100 Hz
1 kHz
10 kHz
100 kHz
1 MHz
10 MHz
100 MHz

FIG. 26

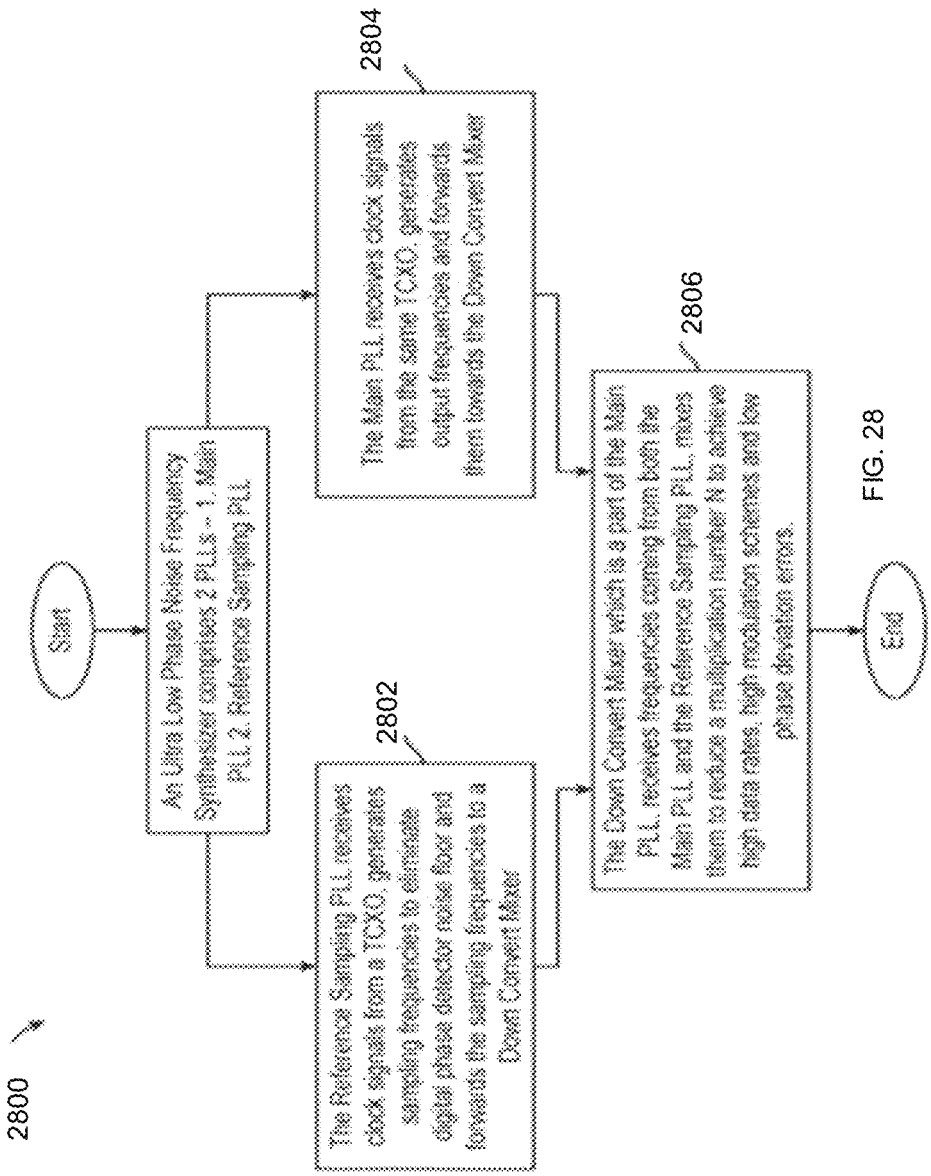
2800
Start
An Ultra Low Phase Noise Frequency Synthesizer comprises 2 PLLs - 1. Main PLL 2. Reference Sampling PLL
2802
The Reference Sampling PLL receives clock signals from a TCXO, generates sampling frequencies to eliminate digital phase detector noise floor and forwards the sampling frequencies to a Down Convert Mixer
2804
The Main PLL receives clock signals from the same TCXO, generates output frequencies and forwards them towards the Down Convert Mixer
2806
The Down Convert Mixer which is a part of the Main PLL, receives frequencies coming from both the Main PLL and the Reference Sampling PLL, mixes them to reduce a multiplication number N to achieve high data rates, high modulation schemes and low phase deviation error.
End

FIG. 28

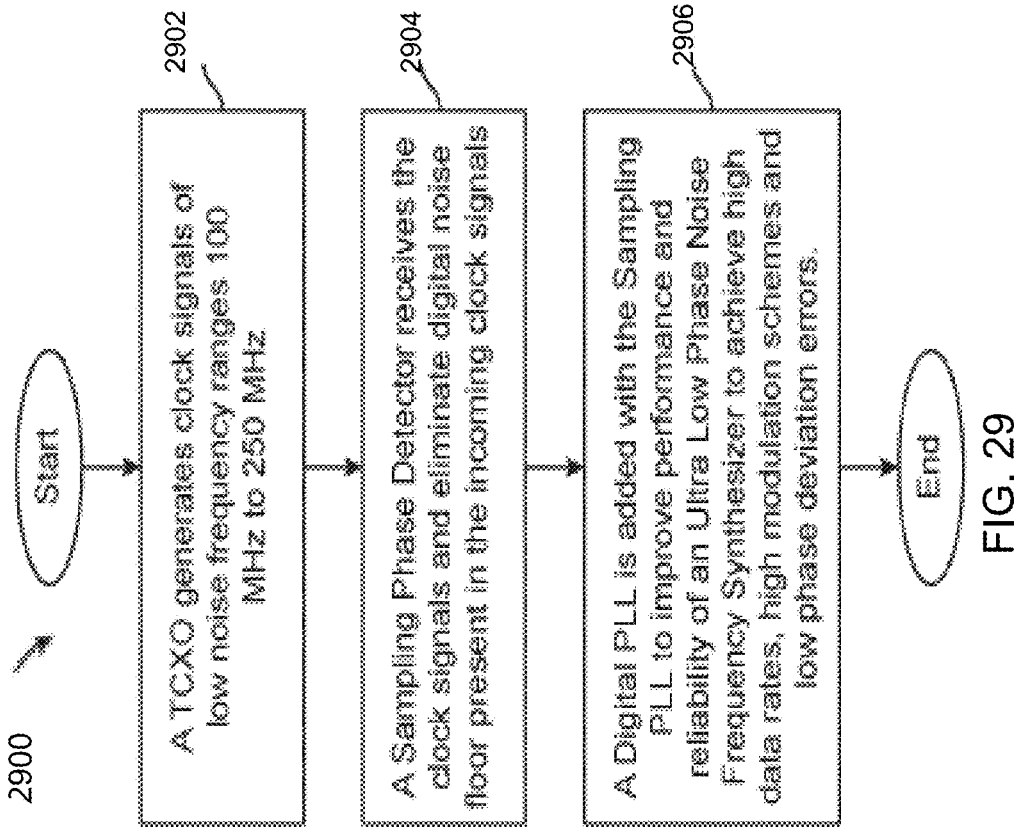
2900
Start
2902
A TCXO generates clock signals of low noise frequency ranges 100 MHz to 250 MHz
2904
A Sampling Phase Detector receives the clock signals and eliminate digital noise floor present in the incoming clock signals
2906
A Digital PLL is added with the Sampling PLL to improve performance and reliability of an Ultra Low Phase Noise Frequency Synthesizer to achieve high data rates, high modulation schemes and low phase deviation errors.
End

FIG. 29

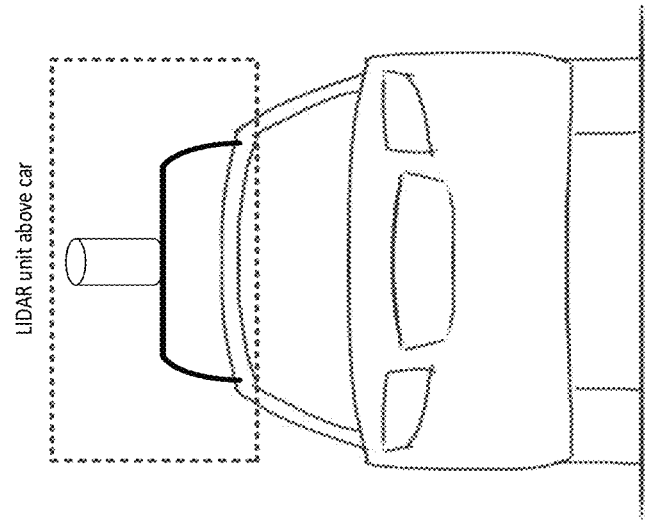

FIG. 30B

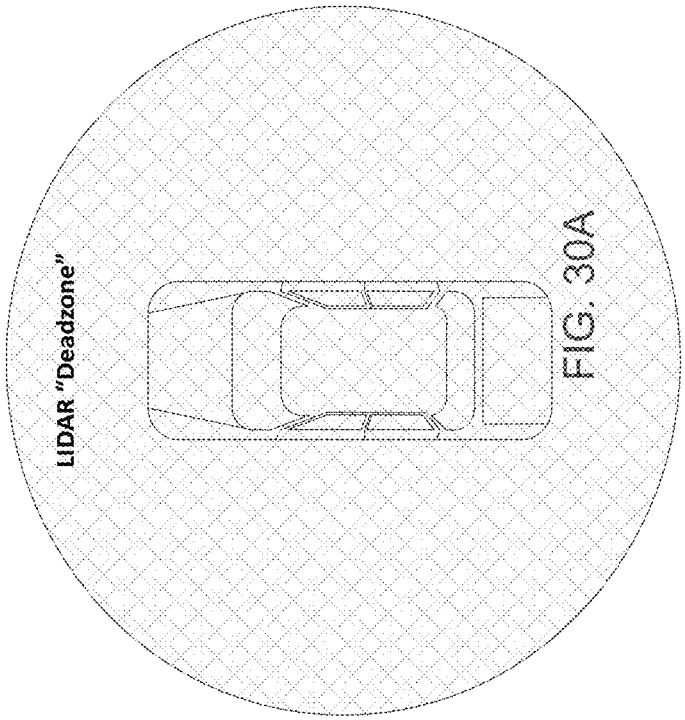

FIG. 30A

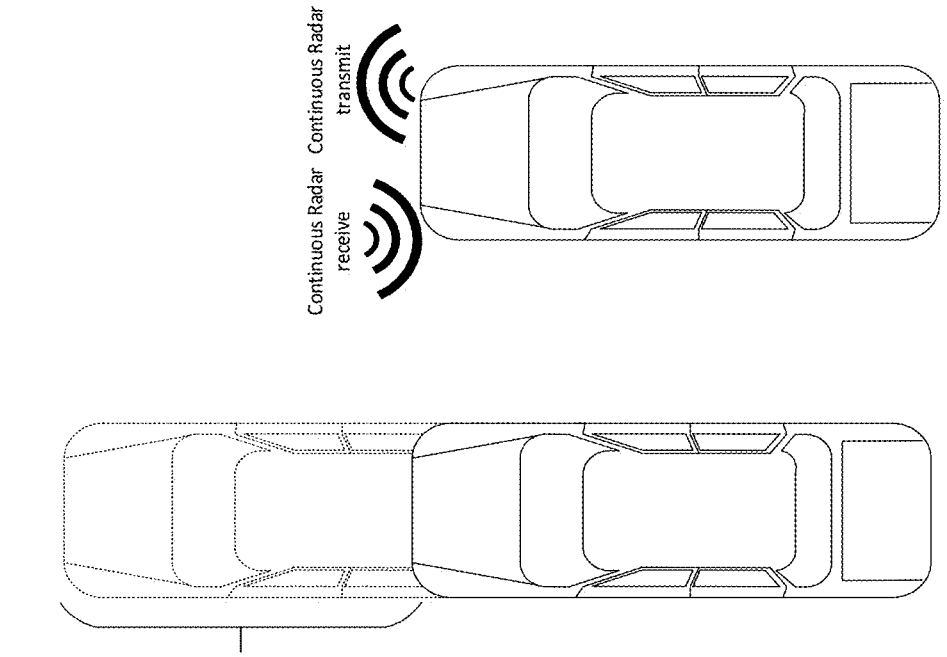

FIG. 32A

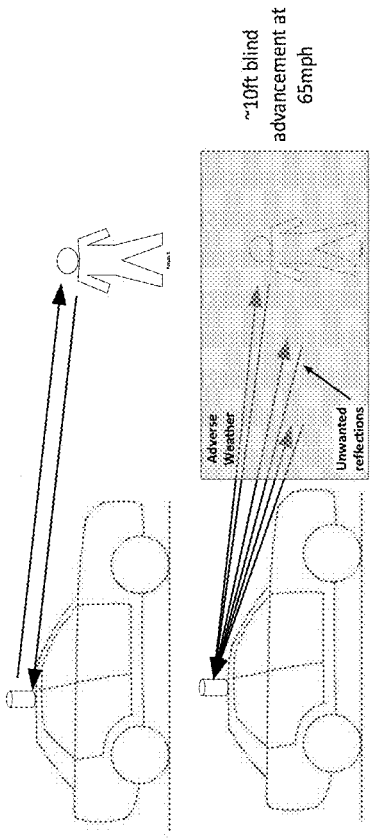

FIG. 31

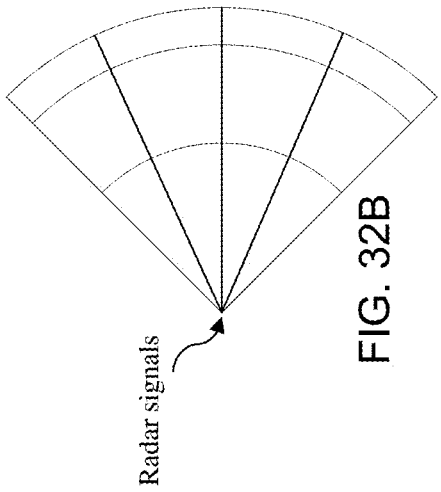

FIG. 32B

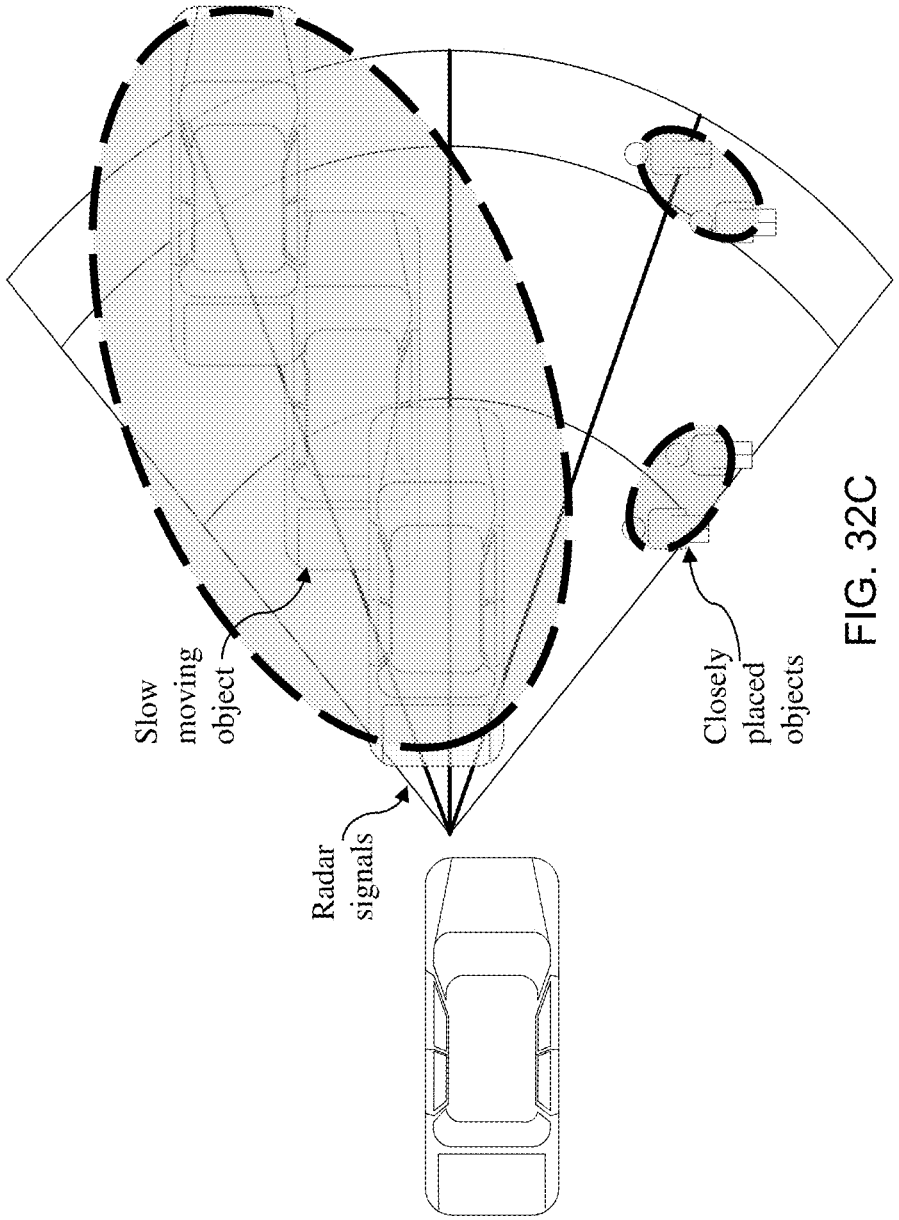

FIG. 32C

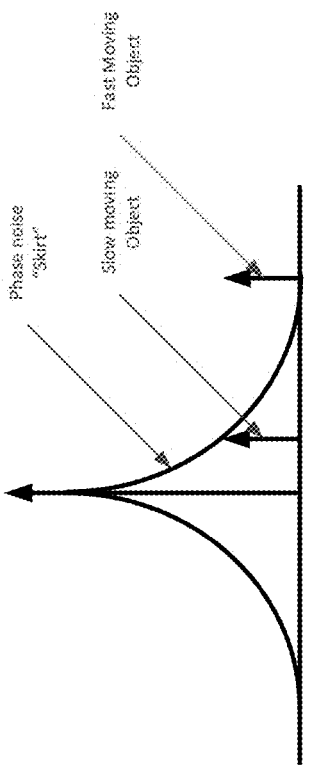

FIG. 34

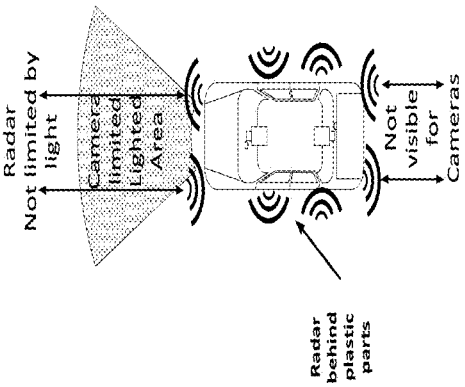

FIG. 33

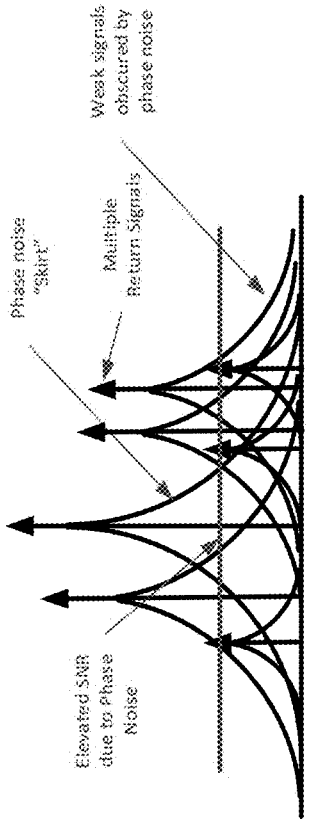

FIG. 36

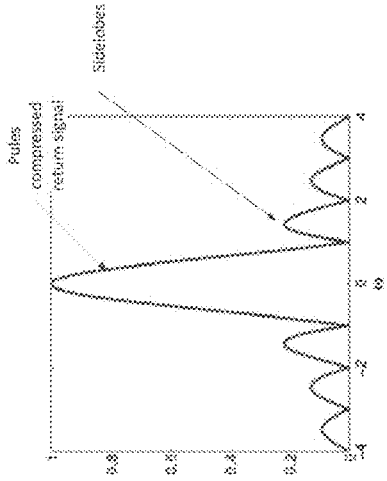

FIG. 35

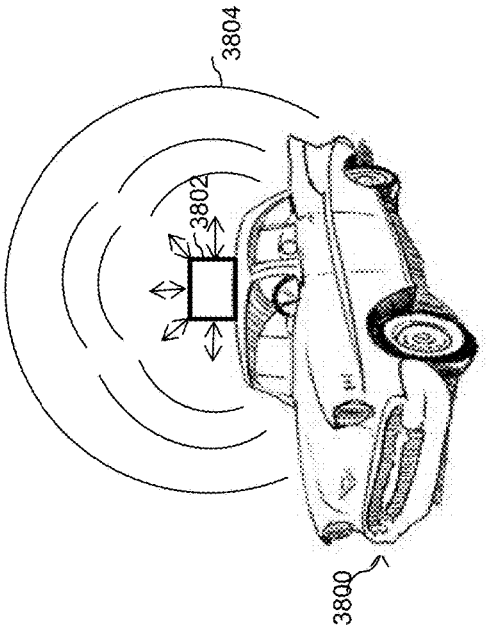

FIG. 38

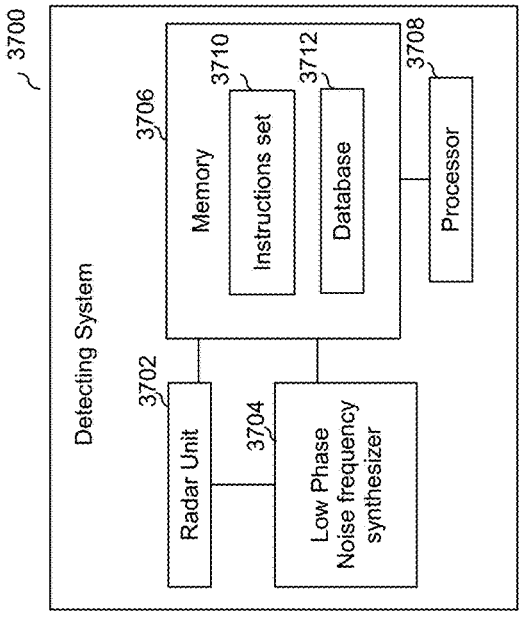

FIG. 37

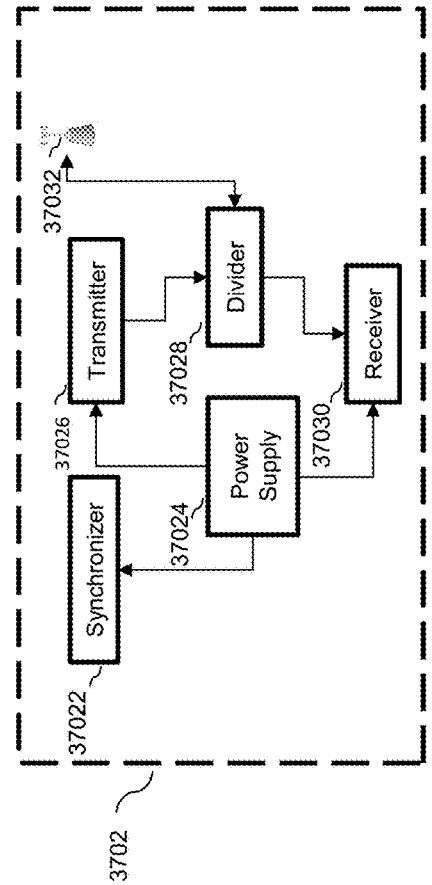

FIG. 39

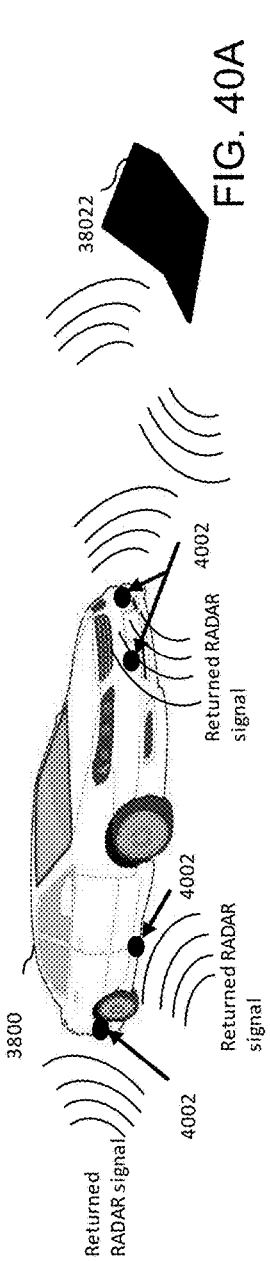

FIG. 40A

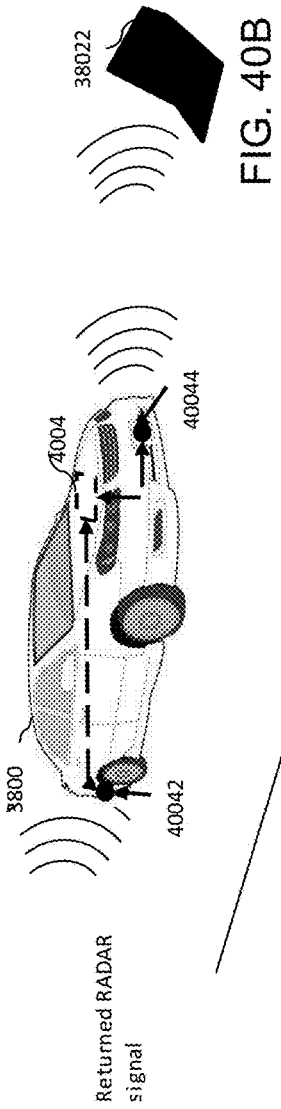

FIG. 40B

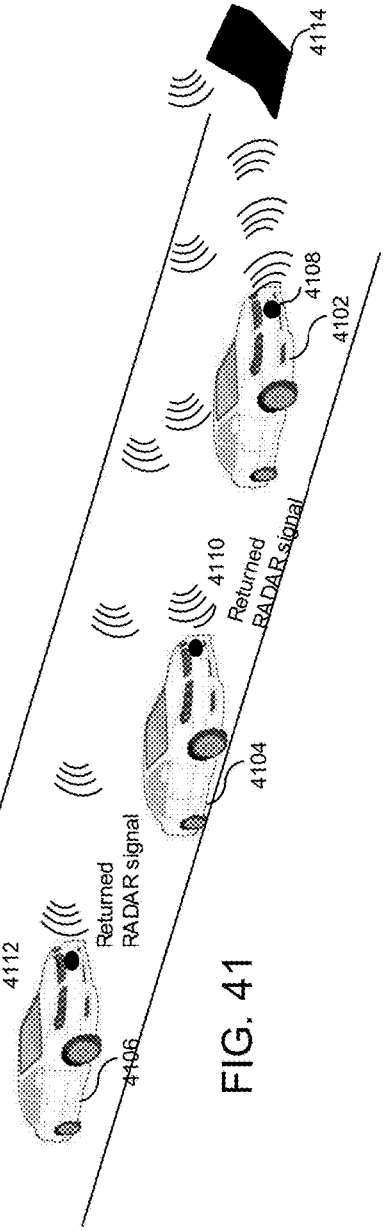

FIG. 41

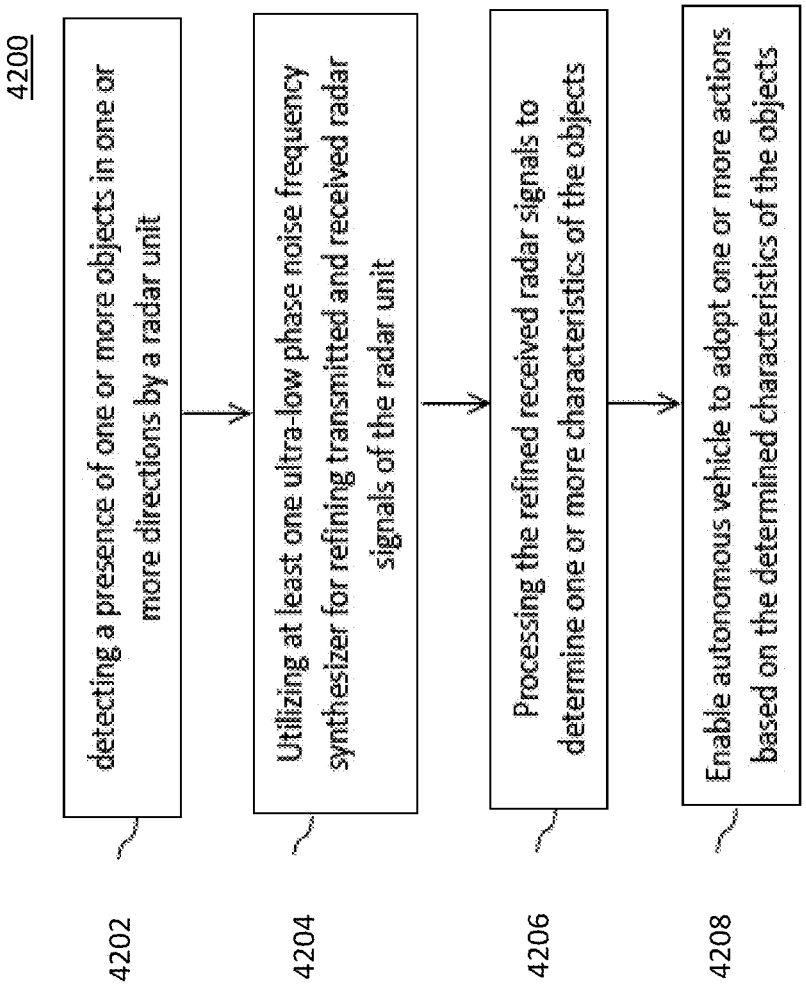
4200
detecting a presence of one or more objects in one or more directions by a radar unit
Utilizing at least one ultra-low phase noise frequency synthesizer for refining transmitted and received radar signals of the radar unit
Processing the refined received radar signals to determine one or more characteristics of the objects
Enable autonomous vehicle to adopt one or more actions based on the determined characteristics of the objects
4202
4204
4206
4208

FIG. 42

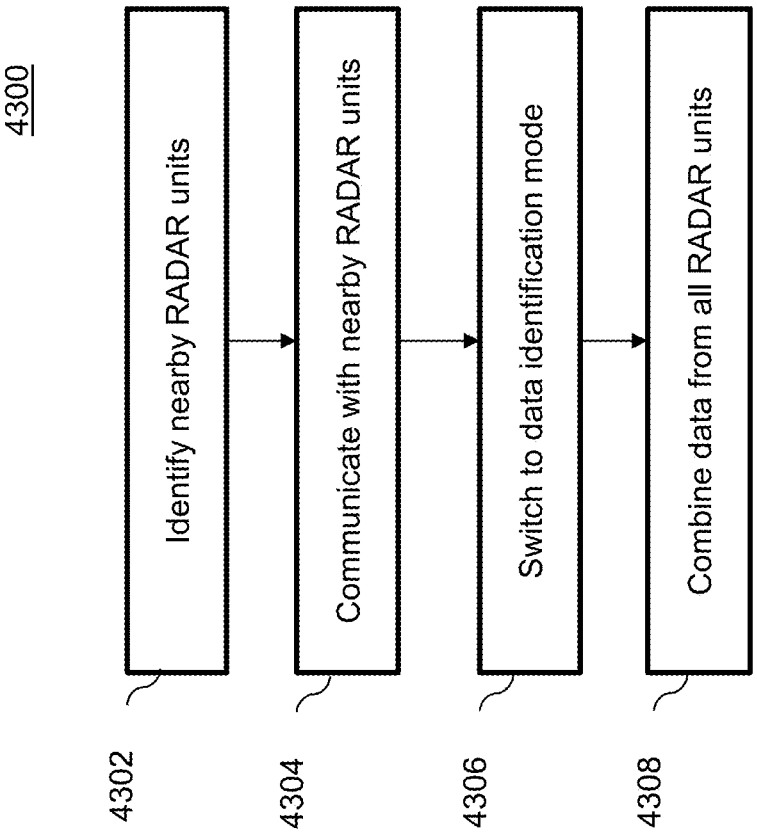
4300
Identify nearby RADAR units
Communicate with nearby RADAR units
Switch to data identification mode
Combine data from all RADAR units
4302
4304
4306
4308

FIG. 43

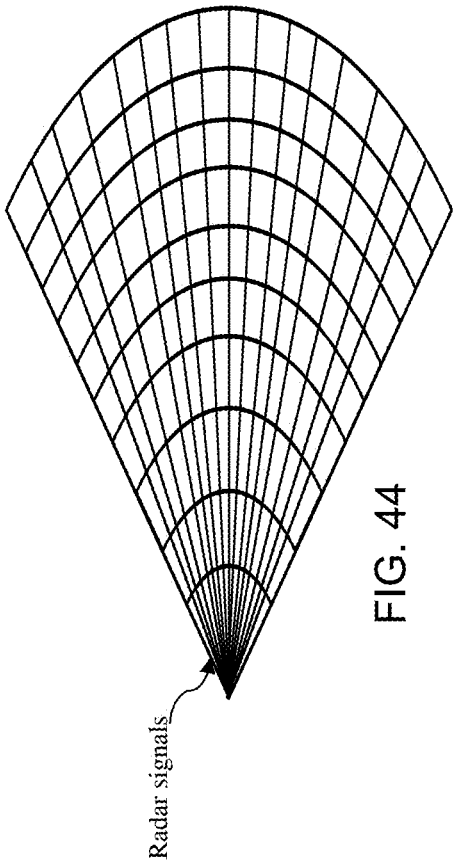
Radar signals

FIG. 44

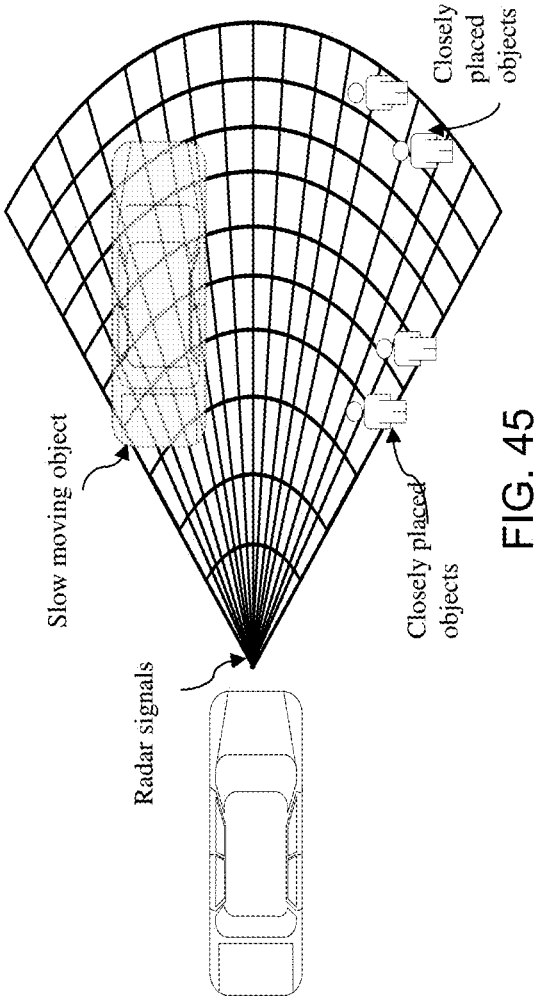
Closely placed objects
Slow moving object
Radar signals
Closely placed objects

FIG. 45

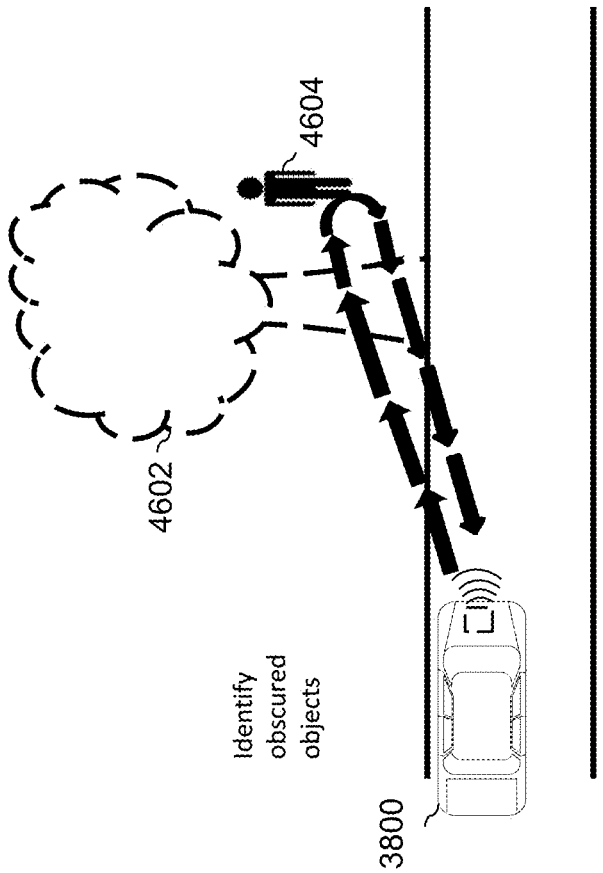

FIG. 46 A

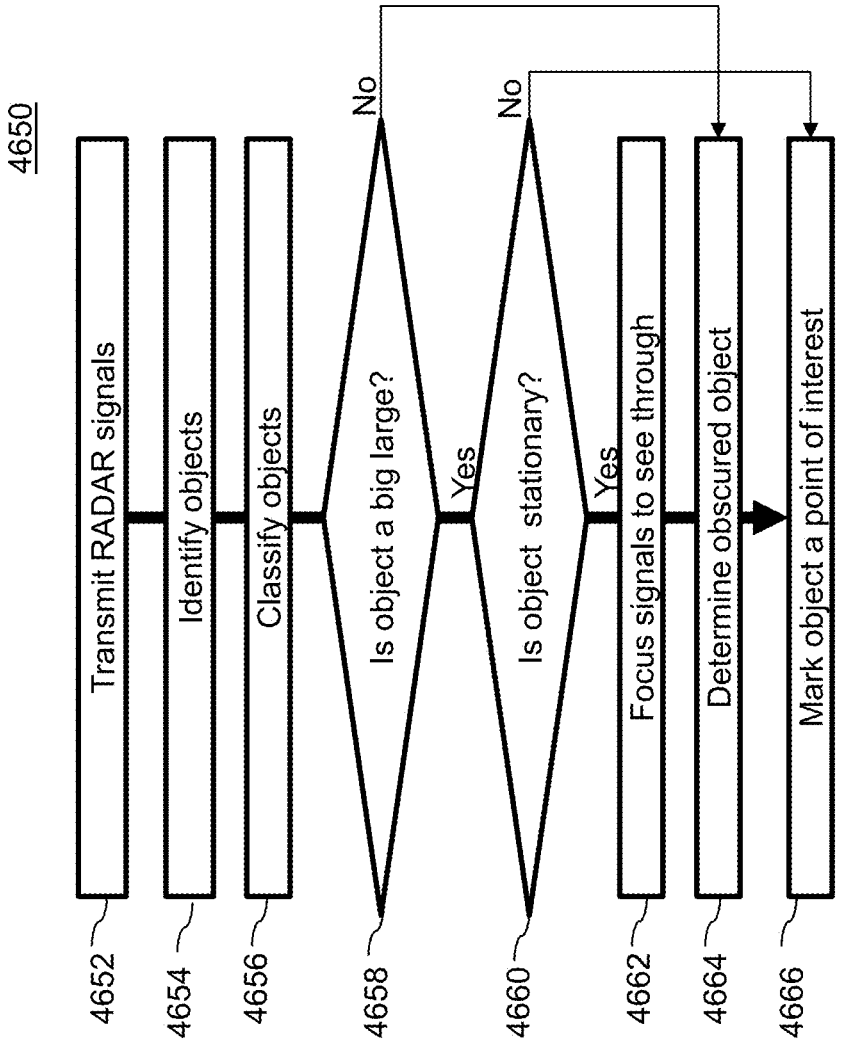
4650
Transmit RADAR signals
Identify objects
Classify objects
Is object a big large?
No
Yes
Is object stationary?
No
Yes
Focus signals to see through
Determine obscured object
Mark object a point of interest
4652
4654
4656
4658
4660
4662
4664
4666

FIG. 46 B

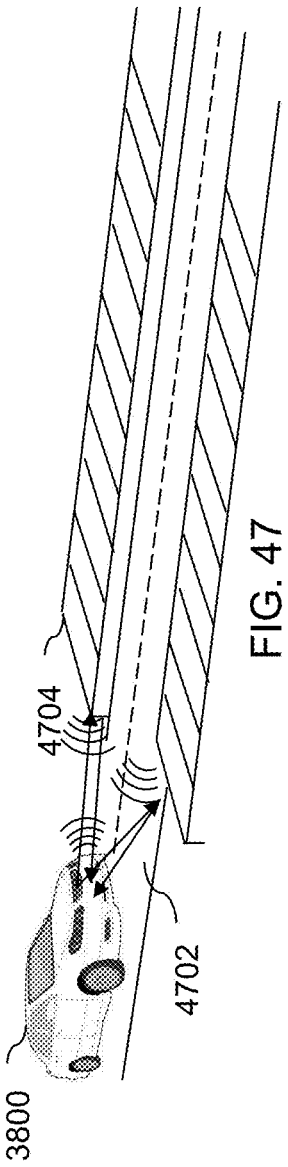
3800
4704
4702

FIG. 47

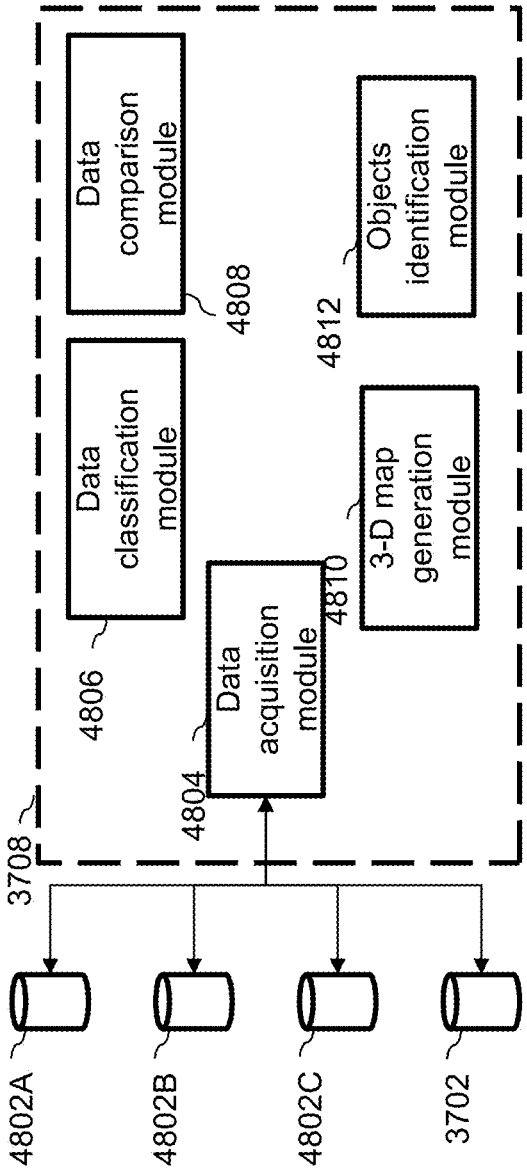
3708
Data comparison module
4808
Data classification module
4806
Data acquisition module
4804
3-D map generation module
4810
Objects identification module
4812
4802A
4802B
4802C
3702

FIG. 48

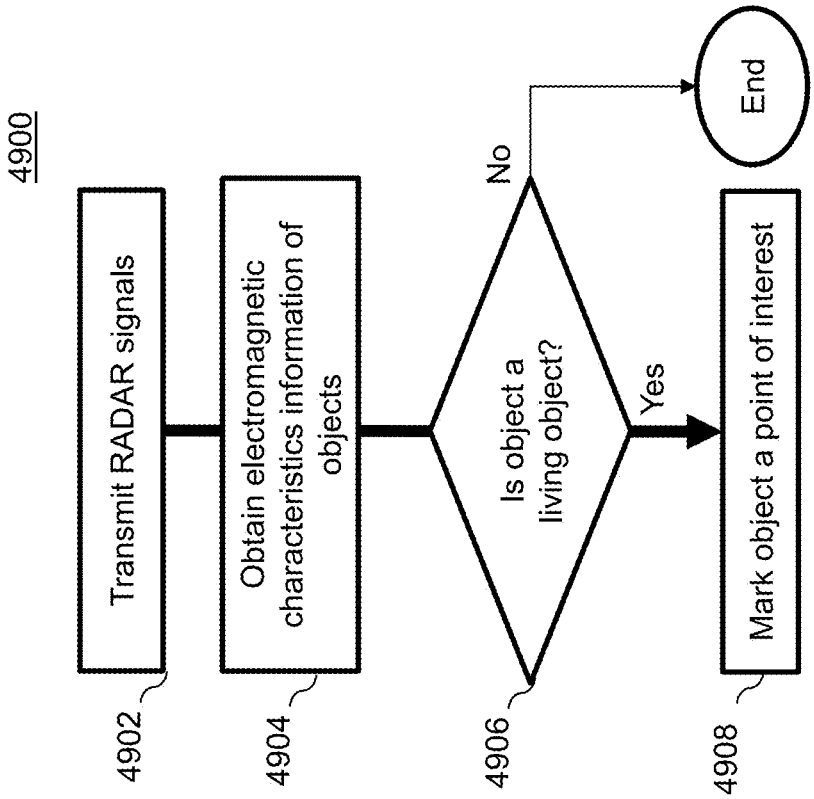
4900
Transmit RADAR signals
Obtain electromagnetic characteristics information of objects
Is object a living object?
No
Yes
End
Mark object a point of interest
4902
4904
4906
4908

FIG. 49

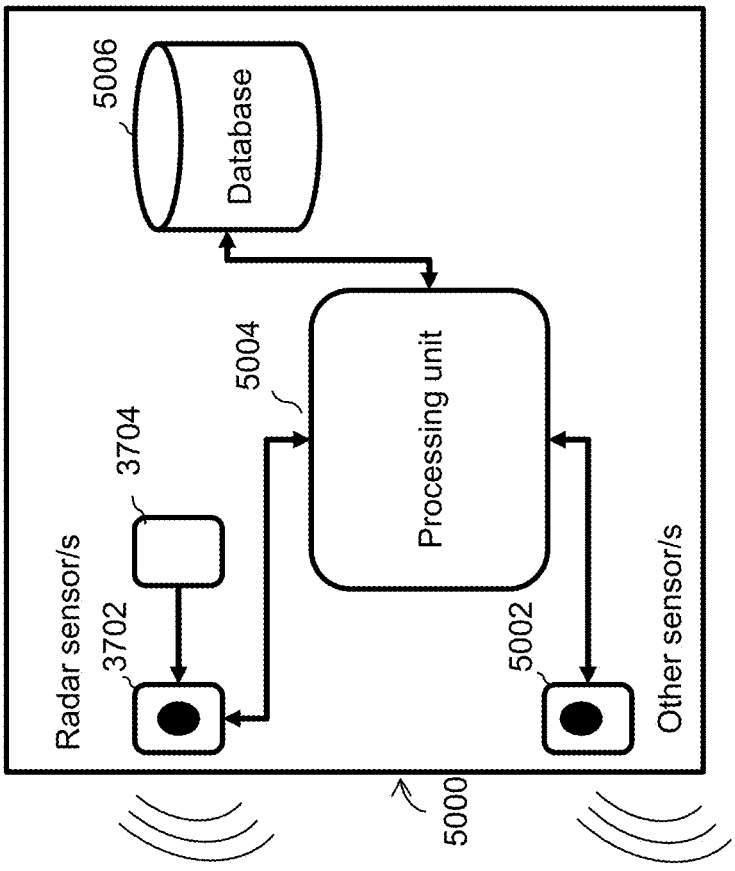
5006
Database
5004
Processing unit
3704
Radar sensor/s
3702
5002
Other sensor/s
5000

FIG. 50

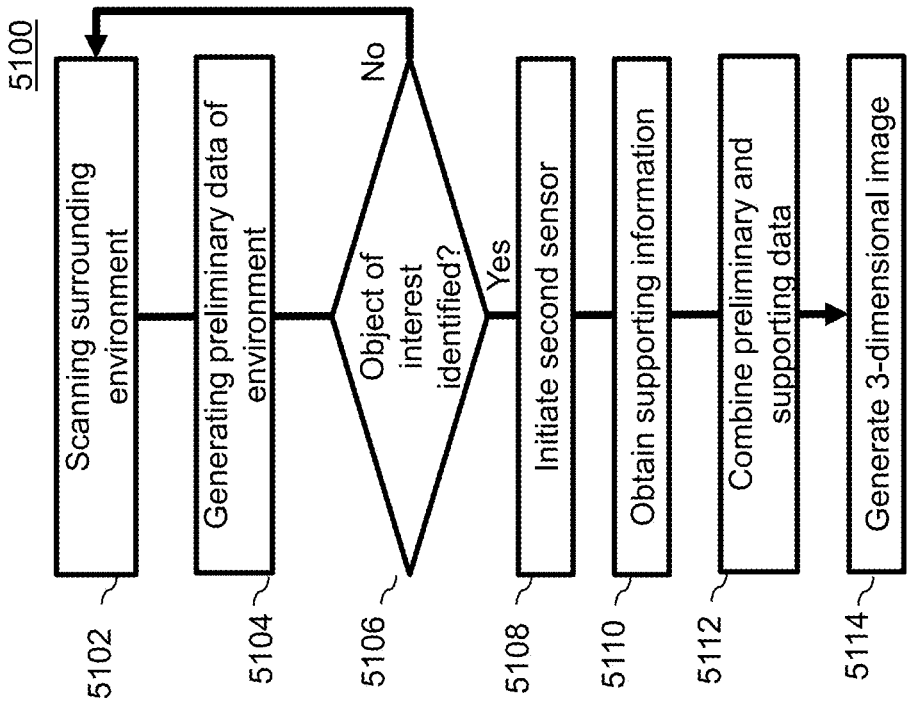
5100
Scanning surrounding environment
Generating preliminary data of environment
Object of interest identified?
No
Yes
Initiate second sensor
Obtain supporting information
Combine preliminary and supporting data
Generate 3-dimensional image
5102
5104
5106
5108
5110
5112
5114

FIG. 51

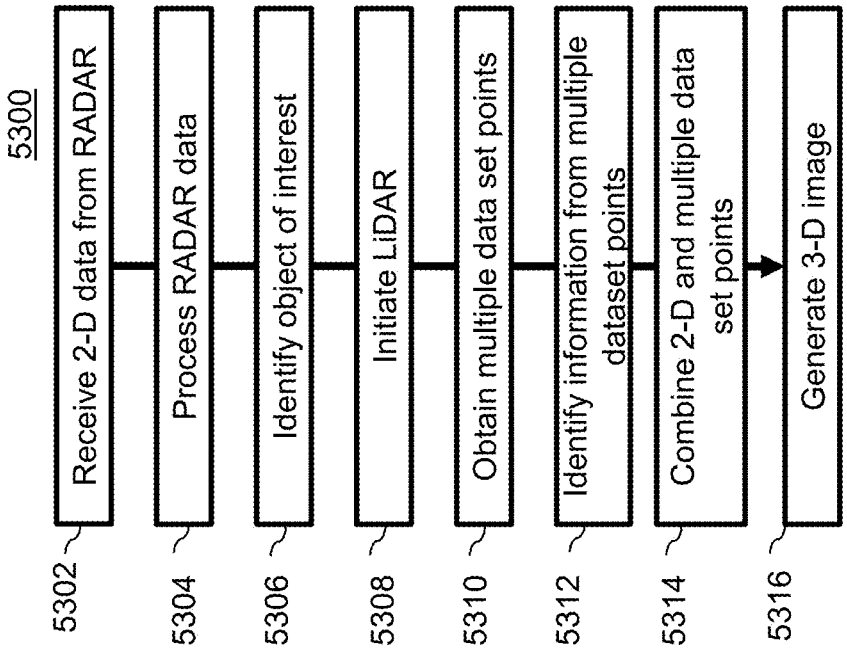
5300
Receive 2-D data from RADAR
Process RADAR data
Identify object of interest
Initiate LiDAR
Obtain multiple data set points
Identify information from multiple dataset points
Combine 2-D and multiple data set points
Generate 3-D image
5302
5304
5306
5308
5310
5312
5314
5316

FIG. 53

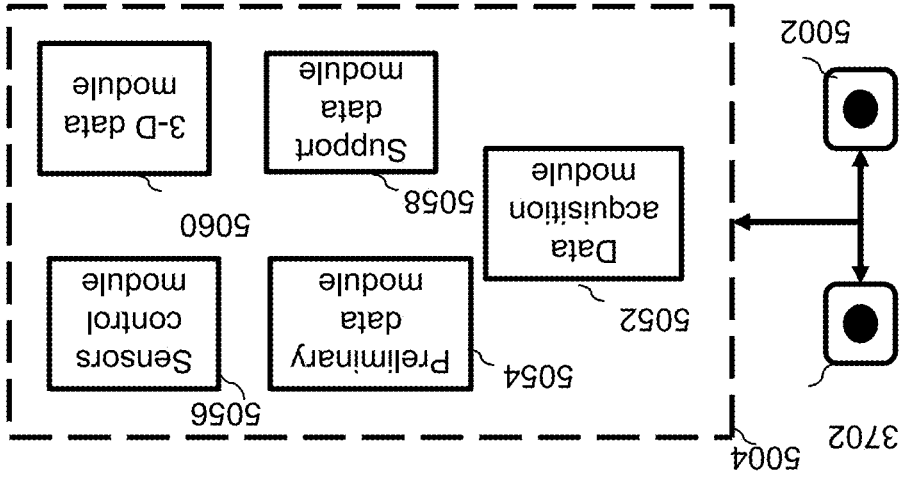
5002
3-D data module
Support data module
Data acquisition module
Sensors control module
Preliminary data module
5060
5058
5052
5056
5054
5004
3702

FIG. 52

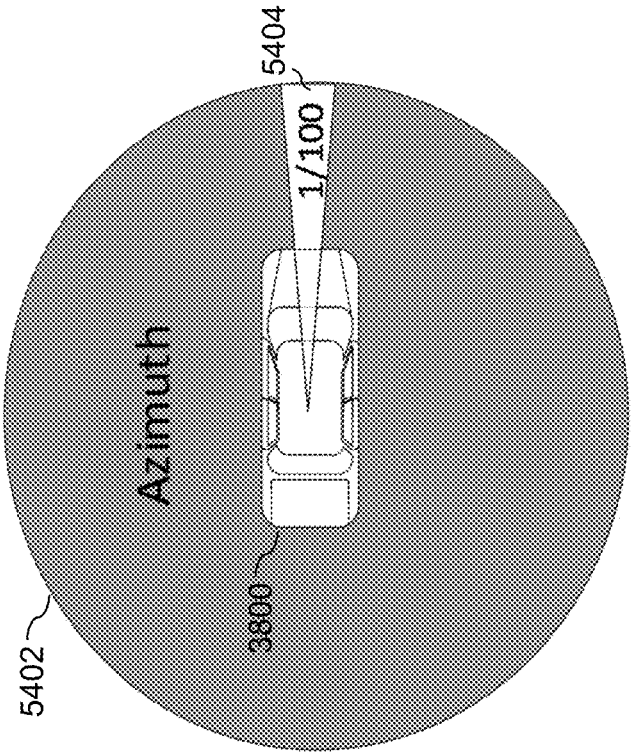

FIG. 54

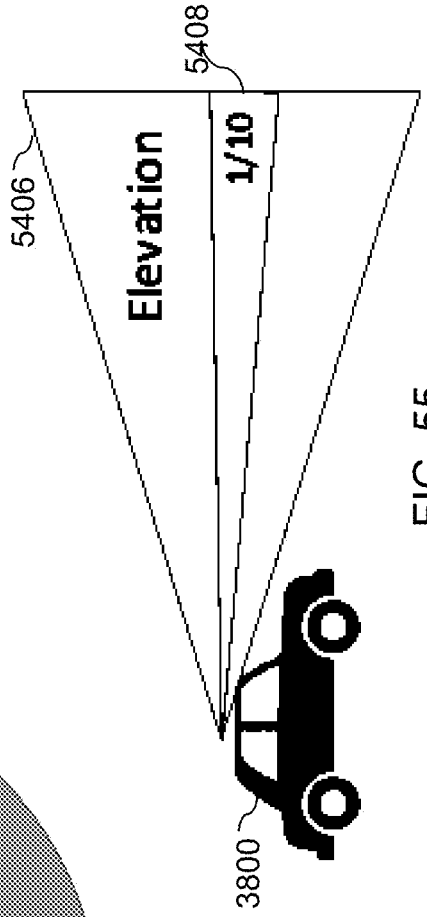

FIG. 55

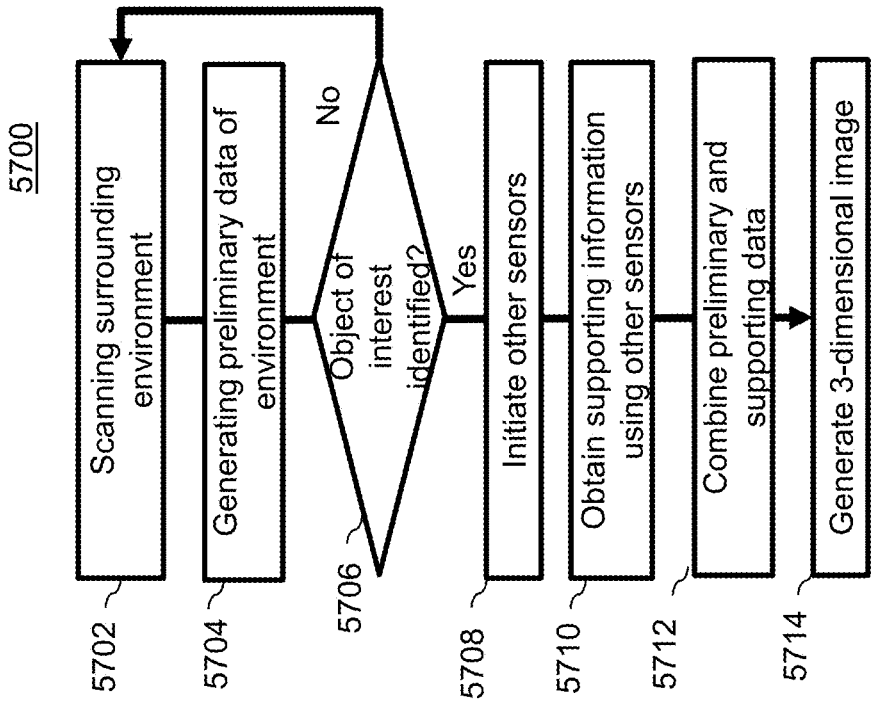
5700
Scanning surrounding environment
Generating preliminary data of environment
Object of interest identified?
No
Yes
Initiate other sensors
Obtain supporting information using other sensors
Combine preliminary and supporting data
Generate 3-dimensional image
5702
5704
5706
5708
5710
5712
5714

FIG. 57

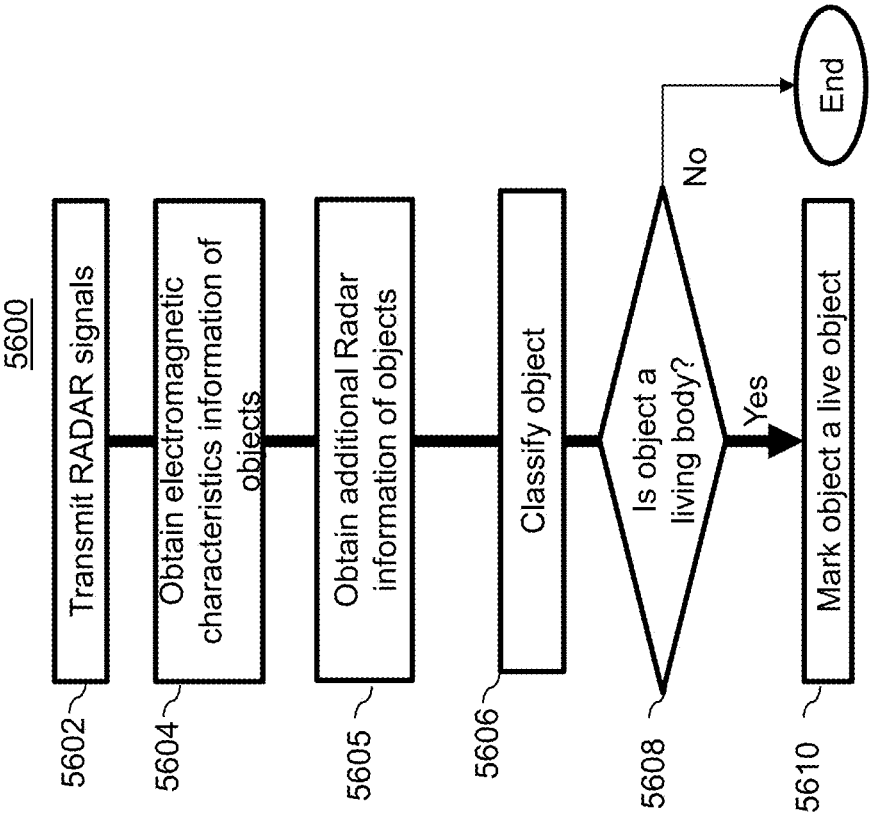
5600
Transmit RADAR signals
Obtain electromagnetic characteristics information of objects
Obtain additional Radar information of objects
Classify object
Is object a living body?
No
Yes
End
Mark object a live object
5602
5604
5605
5606
5608
5610

FIG. 56

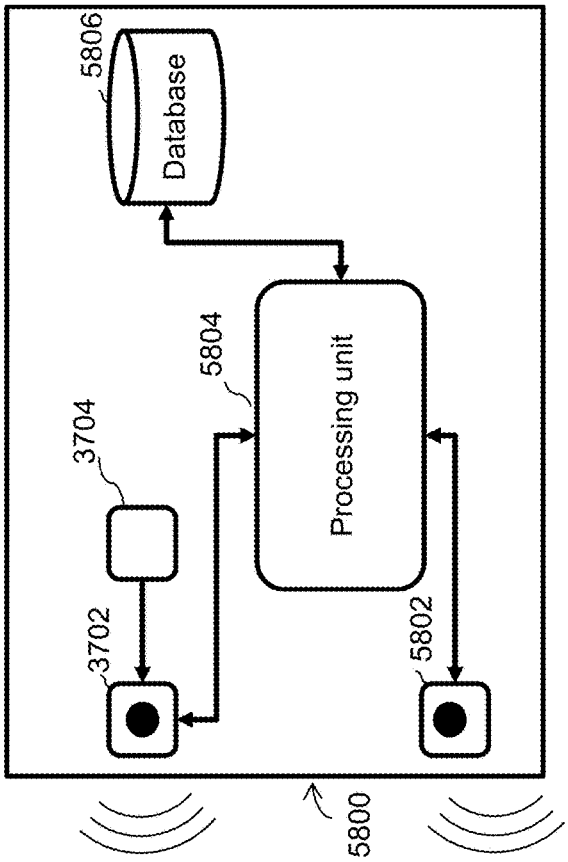
5806
Database
5804
Processing unit
3704
3702
5802
5800

FIG. 58

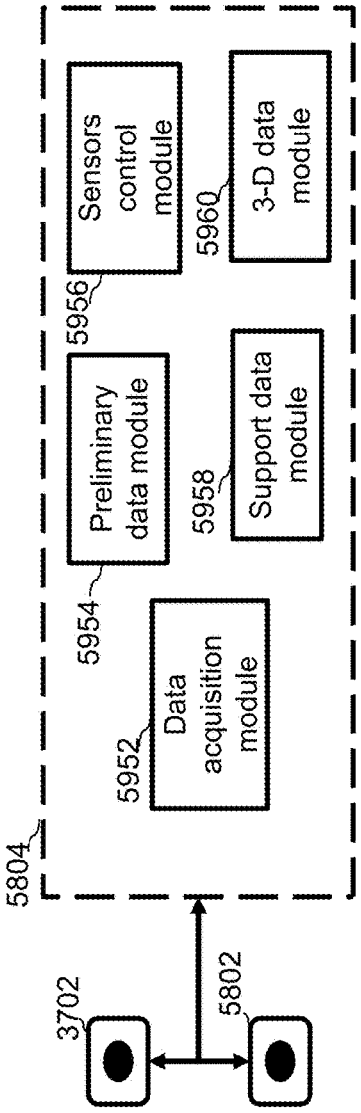
5804
Sensors control module
5956
3-D data module
5960
Preliminary data module
5954
Support data module
5958
Data acquisition module
5952
3702
5802

FIG. 59

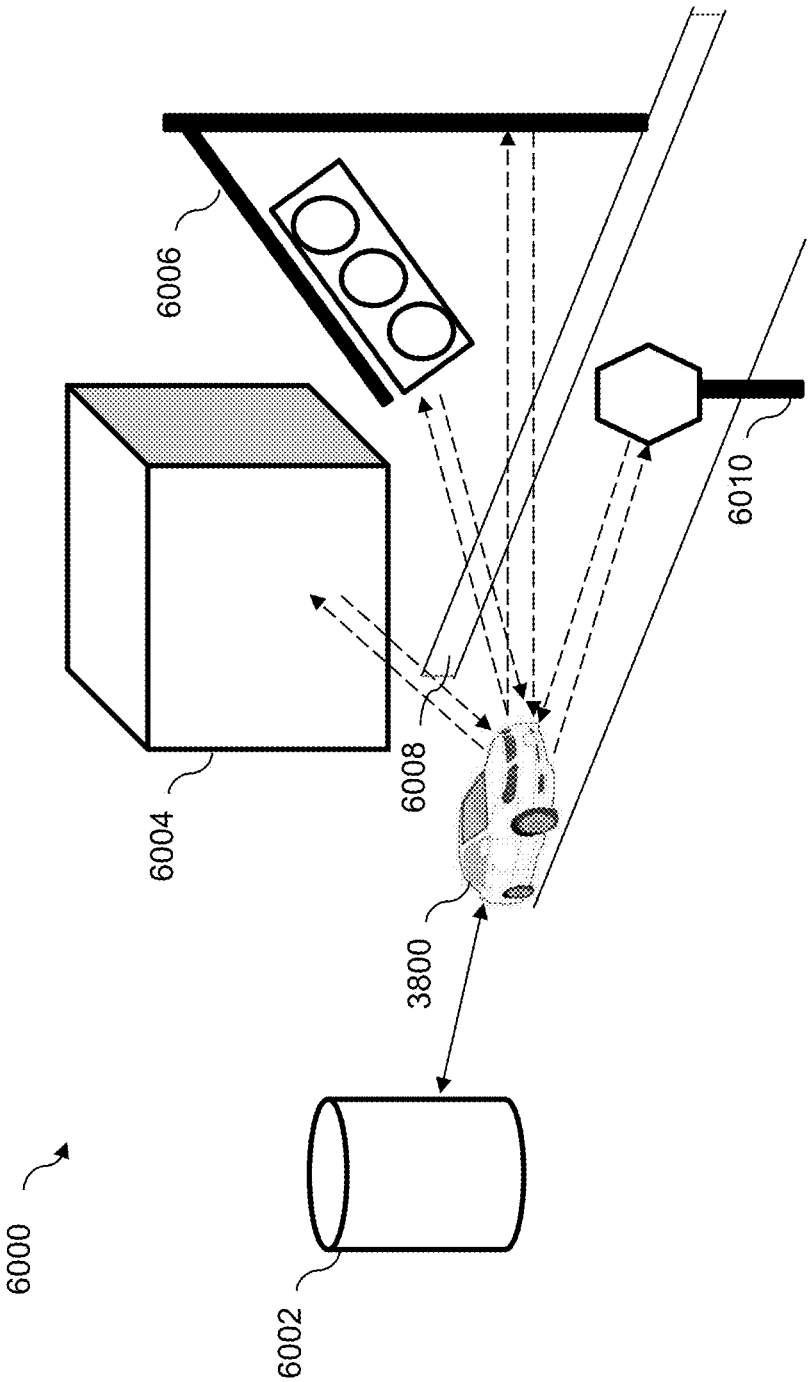

FIG. 60

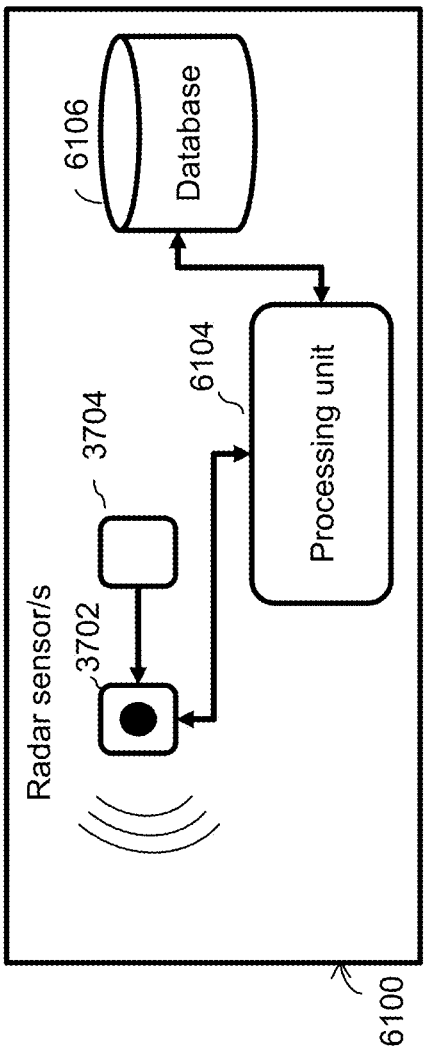
Radar sensor/s
3702
3704
6104
Processing unit
6106
Database
6100

FIG. 61

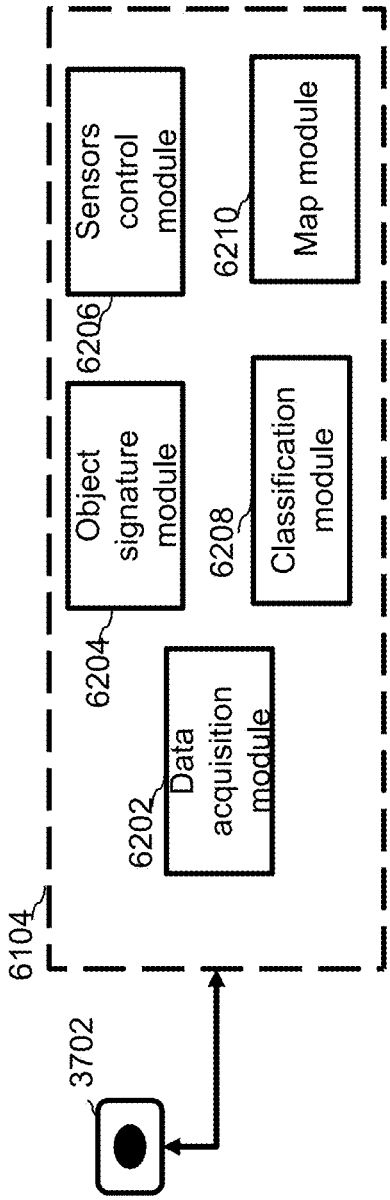
6104
3702
6202
Data acquisition module
6204
Object signature module
6206
Sensors control module
6208
Classification module
6210
Map module

FIG. 62

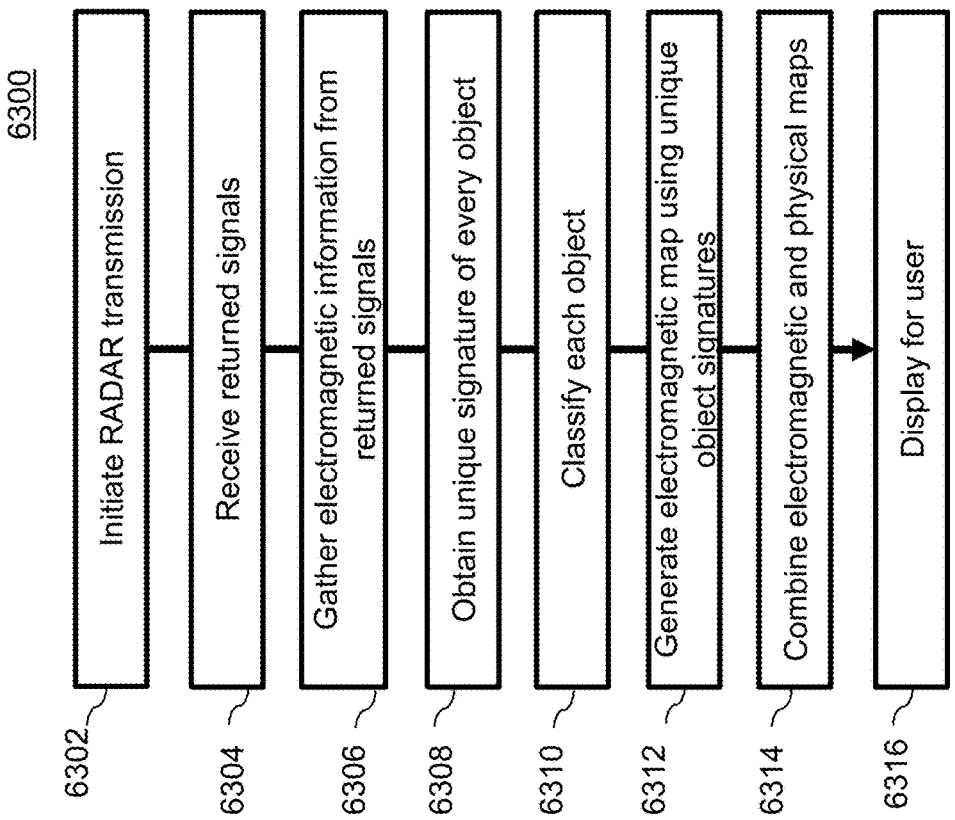
6300
Initiate RADAR transmission
Receive returned signals
Gather electromagnetic information from returned signals
Obtain unique signature of every object
Classify each object
Generate electromagnetic map using unique object signatures
Combine electromagnetic and physical maps
Display for user
6302
6304
6306
6308
6310
6312
6314
6316

FIG. 63

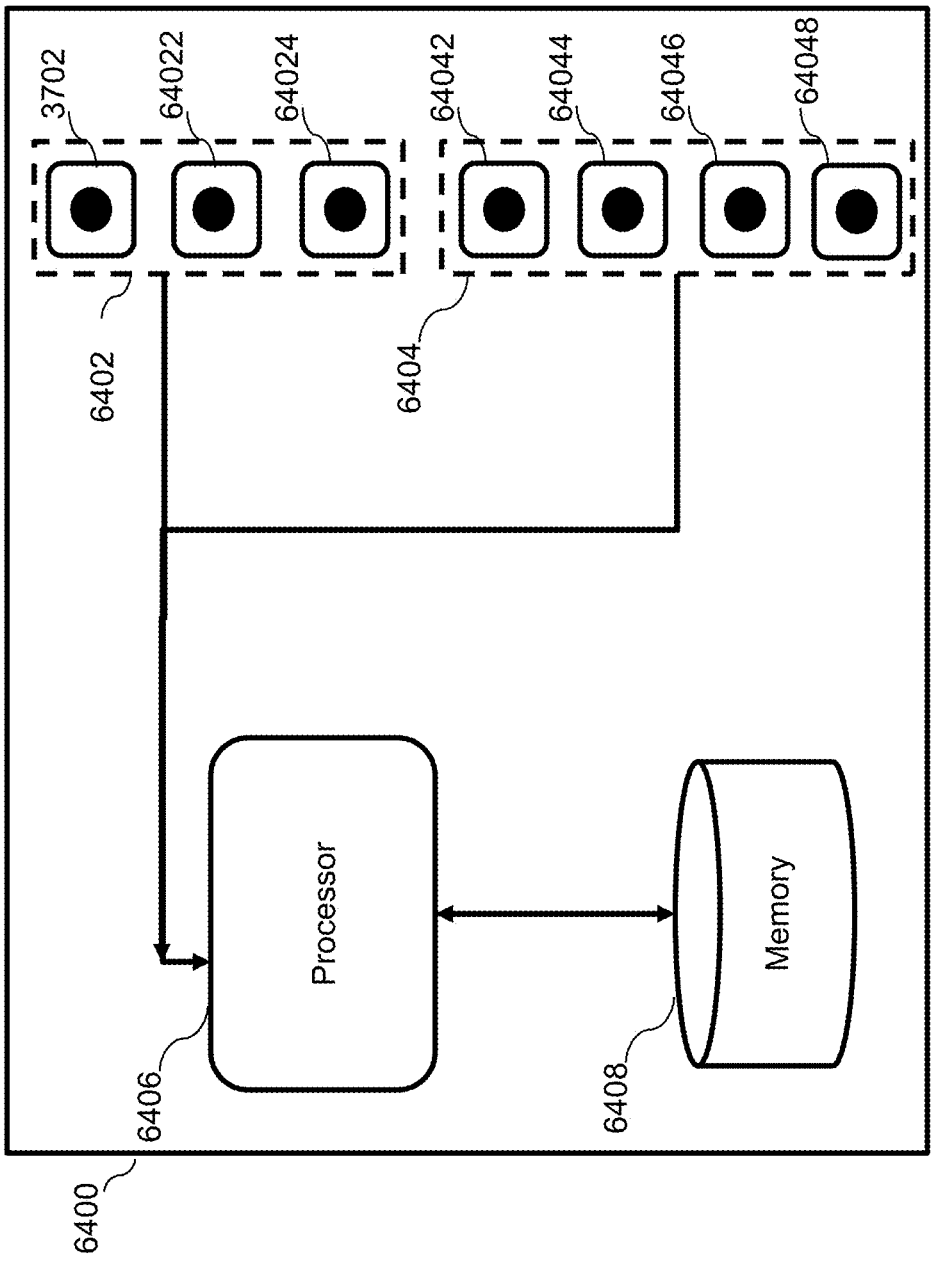
3702
64022
64024
64042
64044
64046
64048
6402
6404
Processor
Memory
6406
6408
6400

FIG. 64

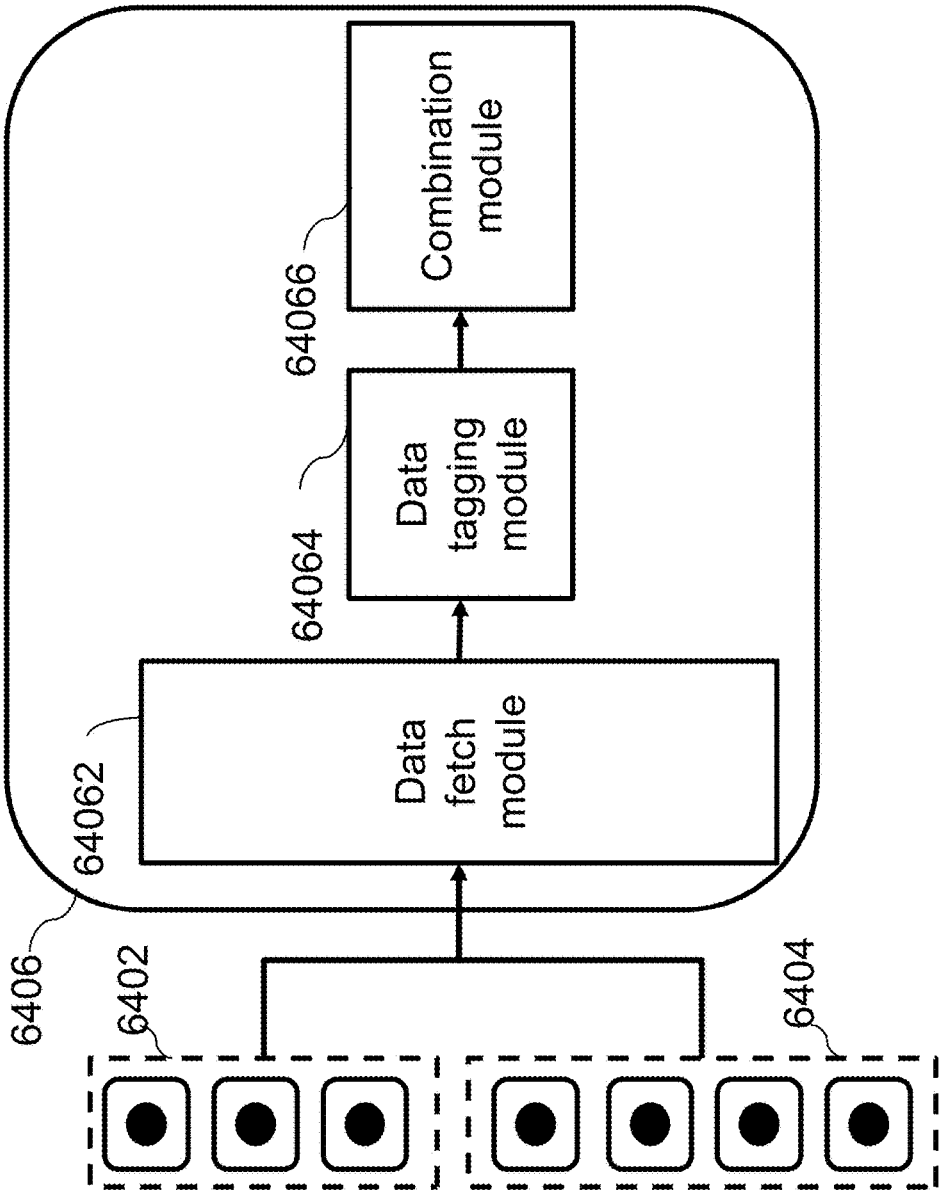
Combination module
64066
Data tagging module
64064
Data fetch module
64062
6406
6402
6404

FIG. 65A

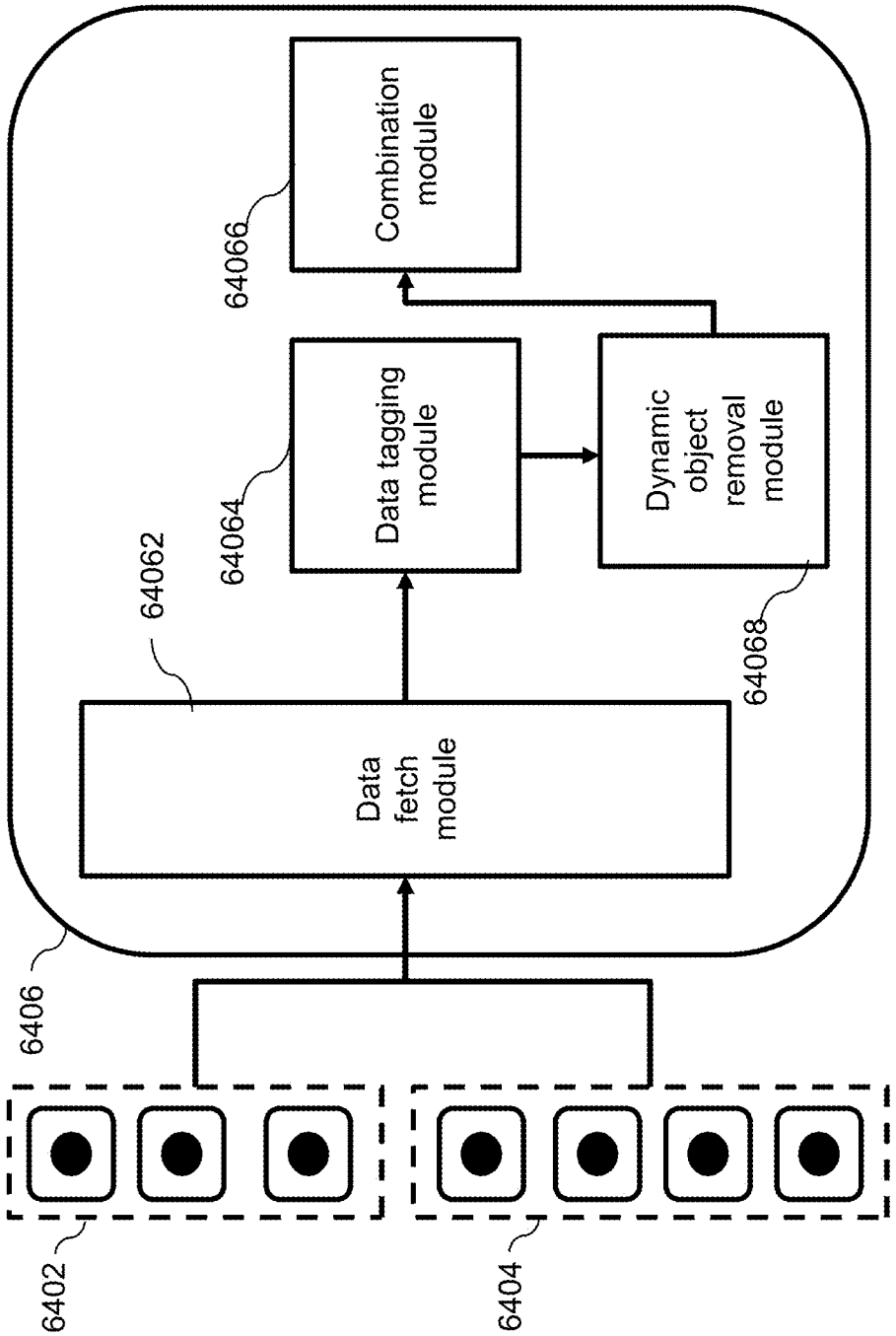
Combination module
64066
Data tagging module
64064
Dynamic object removal module
64068
64062
Data fetch module
6406
6402
6404

FIG. 65B

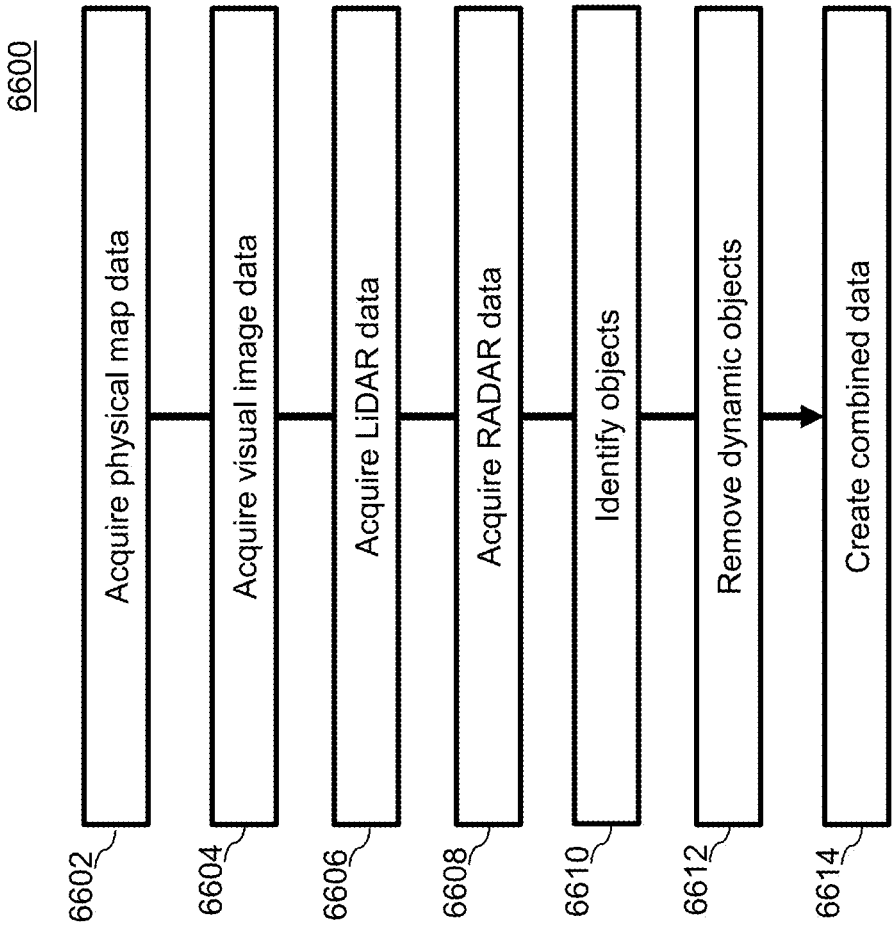
6600
Acquire physical map data
Acquire visual image data
Acquire LiDAR data
Acquire RADAR data
Identify objects
Remove dynamic objects
Create combined data
6602
6604
6606
6608
6610
6612
6614

FIG. 66

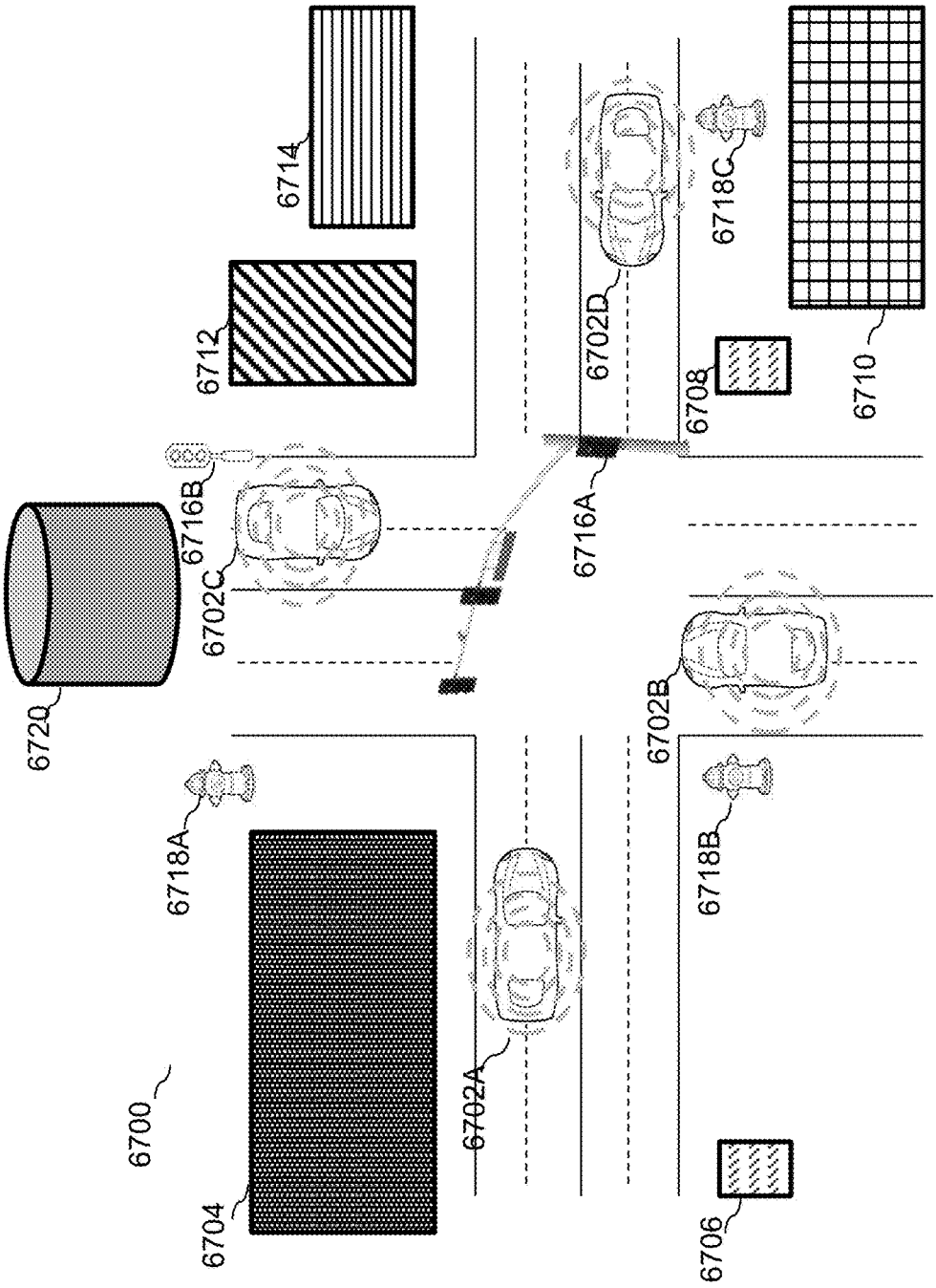
6714
6712
6716B
6702C
6720
6718A
6700
6704
6702A
6716A
6702D
6718C
6708
6710
6702B
6718B
6706

FIG. 67A

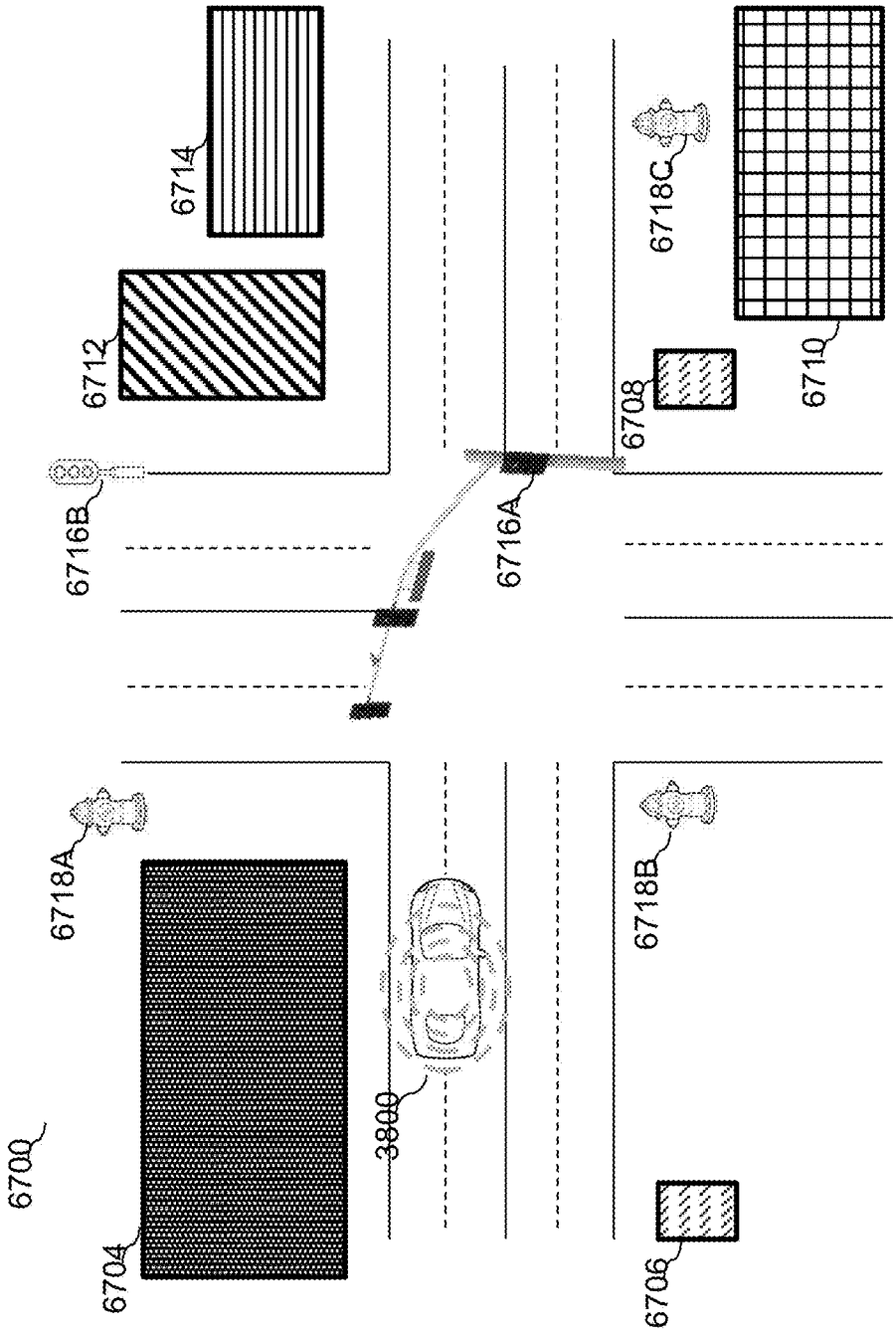
6700
6704
6706
6708
6710
6712
6714
6716A
6716B
6718A
6718B
6718C
3800

FIG. 67B

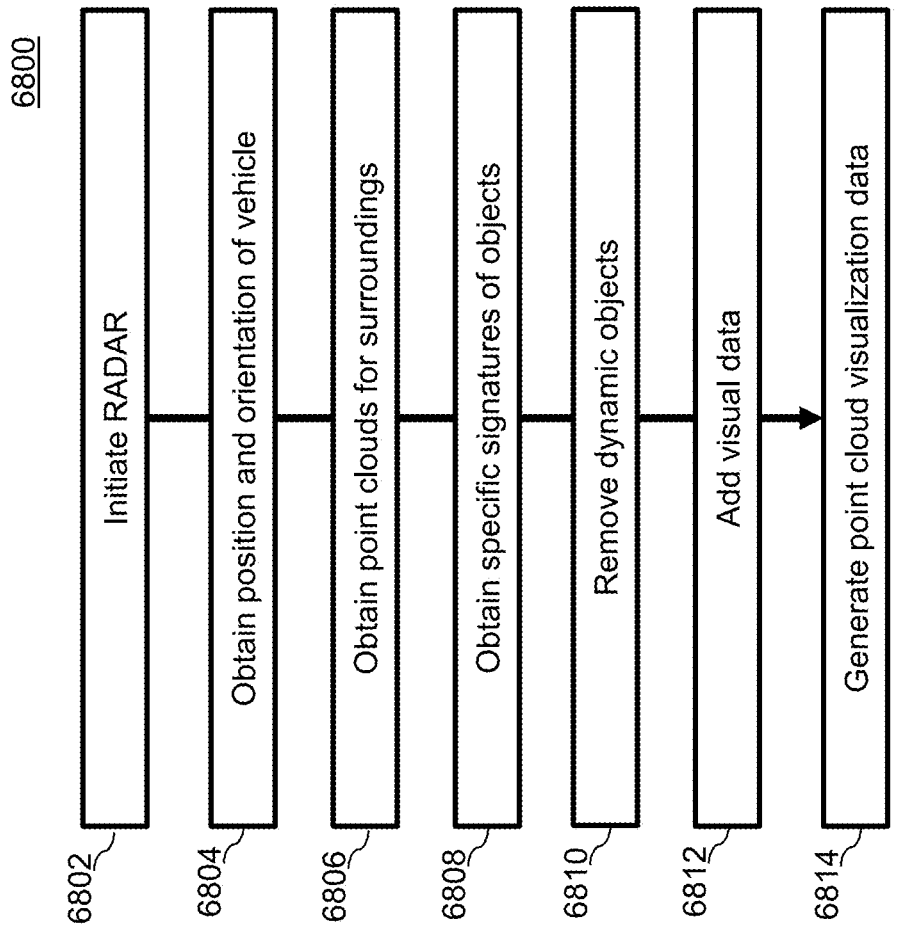
6800
Initiate RADAR
Obtain position and orientation of vehicle
Obtain point clouds for surroundings
Obtain specific signatures of objects
Remove dynamic objects
Add visual data
Generate point cloud visualization data
6802
6804
6806
6808
6810
6812
6814

FIG. 68

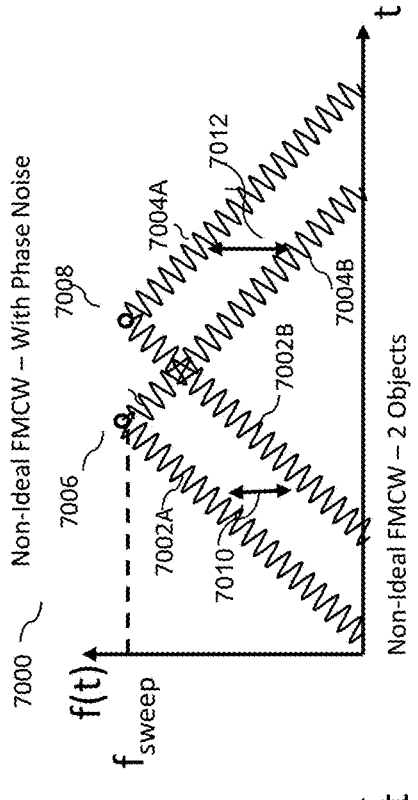

FIG. 70

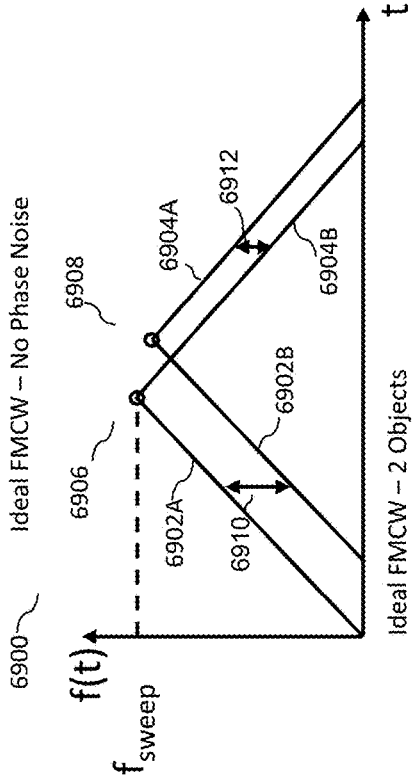

FIG. 69

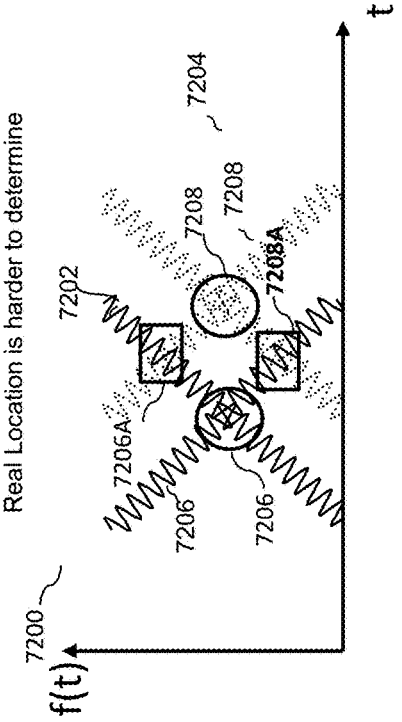

FIG. 72

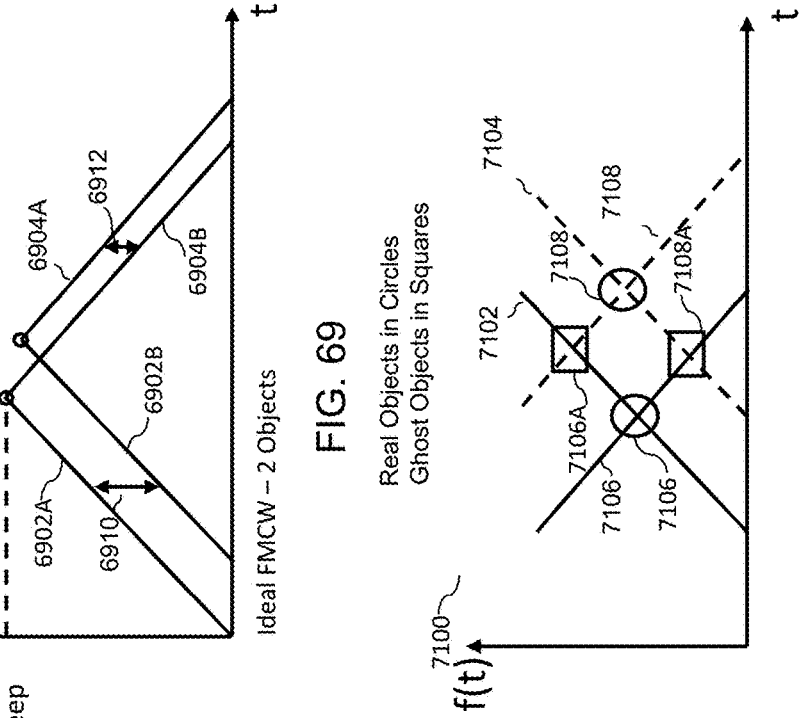

FIG. 71

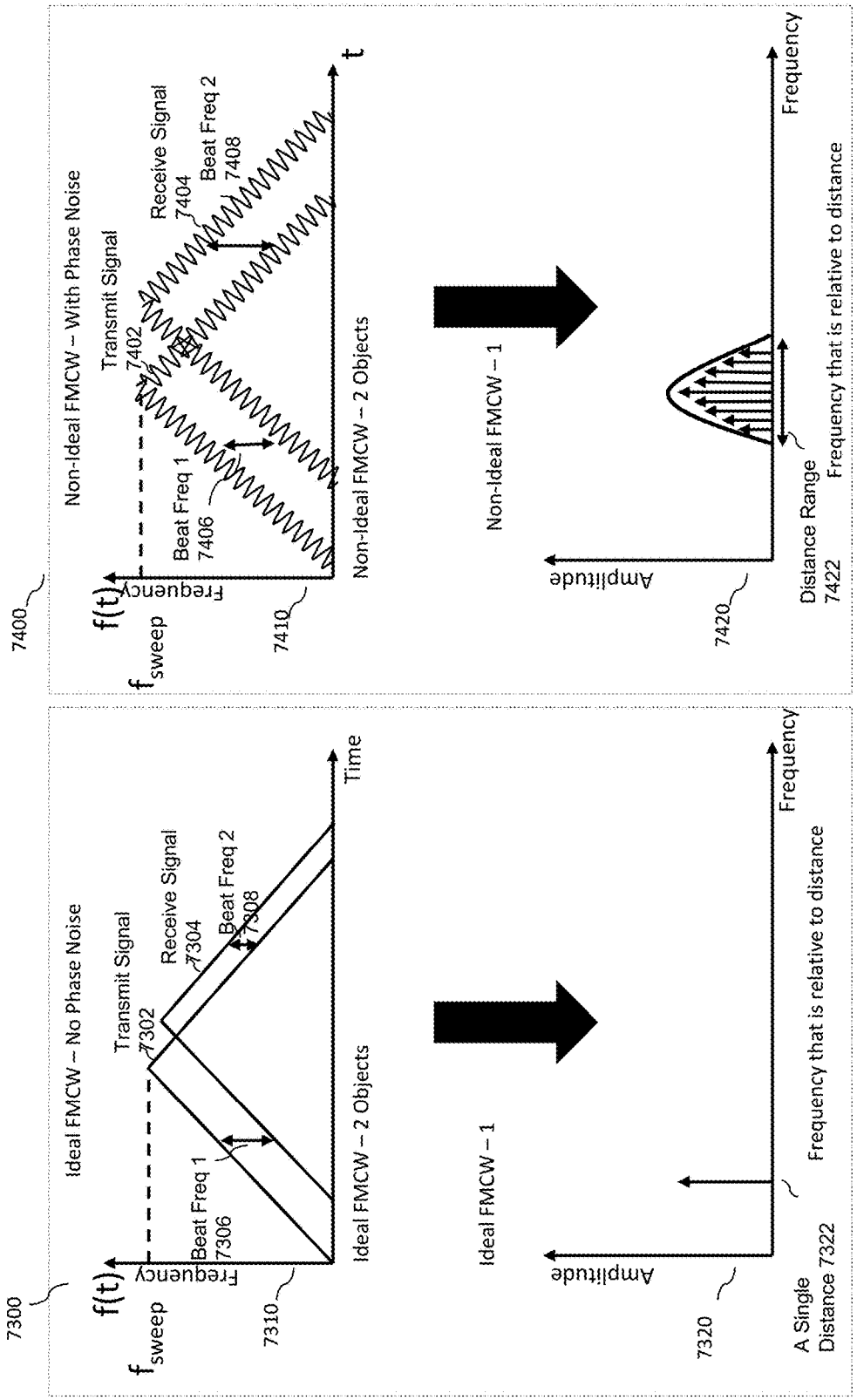
7300
Ideal FMCW – No Phase Noise
f(t)
Frequency
f sweep
Transmit Signal
7302
Receive Signal
7304
Beat Freq 1
7306
Beat Freq 2
7308
Time
7310
Ideal FMCW – 2 Objects
Ideal FMCW – 1
Amplitude
7320
A Single Distance 7322
Frequency
Frequency that is relative to distance
7400
Non-Ideal FMCW – With Phase Noise
f(t)
Frequency
f sweep
Transmit Signal
7402
Receive Signal
7404
Beat Freq 1
7406
Beat Freq 2
7408
t
7410
Non-Ideal FMCW – 2 Objects
Non-Ideal FMCW – 1
Amplitude
7420
Distance Range
7422
Frequency
Frequency that is relative to distance

FIG. 73

FIG. 74

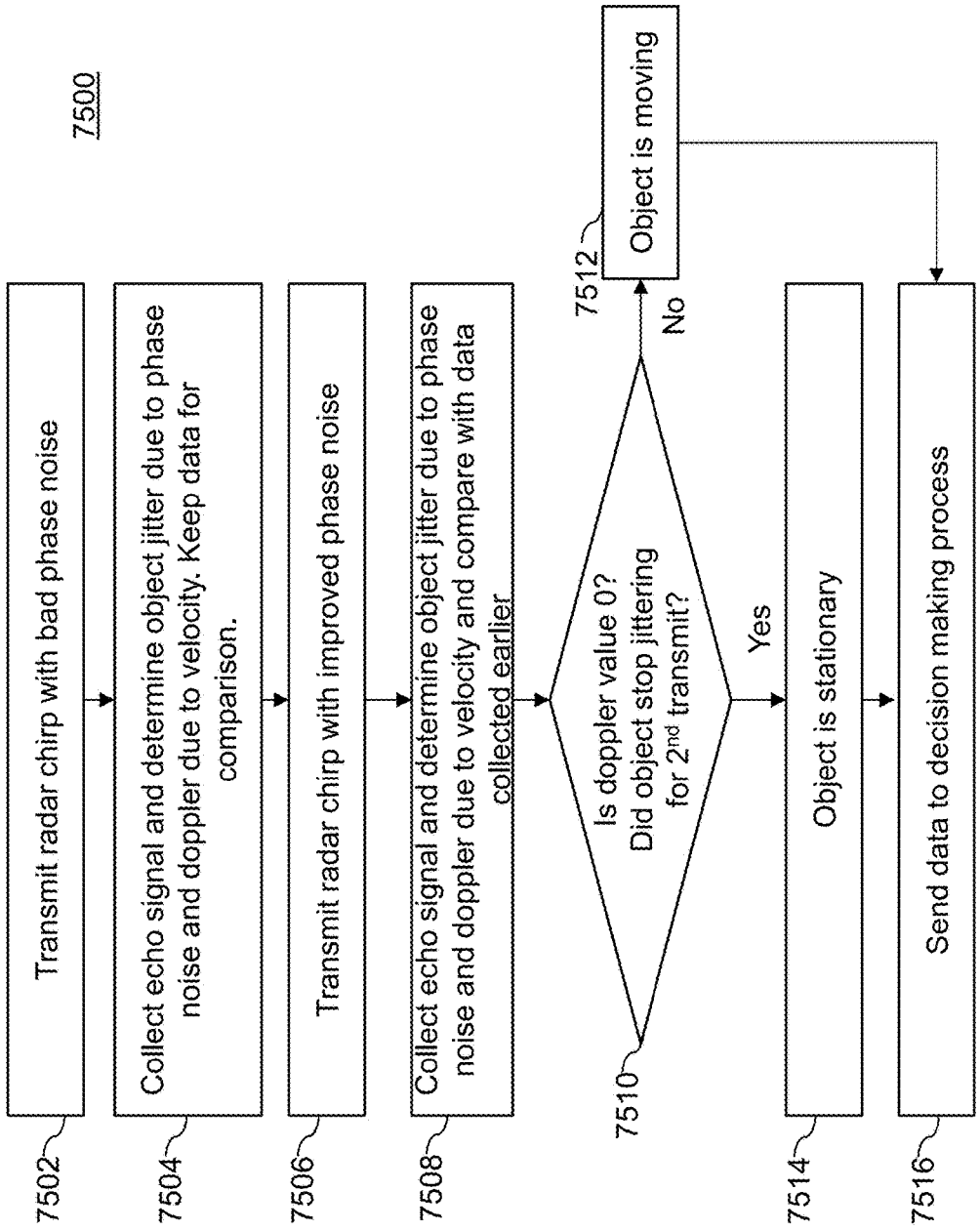
7500
Transmit radar chirp with bad phase noise
Collect echo signal and determine object jitter due to phase noise and doppler due to velocity. Keep data for comparison.
Transmit radar chirp with improved phase noise
Collect echo signal and determine object jitter due to phase noise and doppler due to velocity and compare with data collected earlier
Is doppler value 0? Did object stop jittering for 2nd transmit?
No
Yes
Object is moving
Object is stationary
Send data to decision making process
7502
7504
7506
7508
7510
7512
7514
7516

FIG. 75

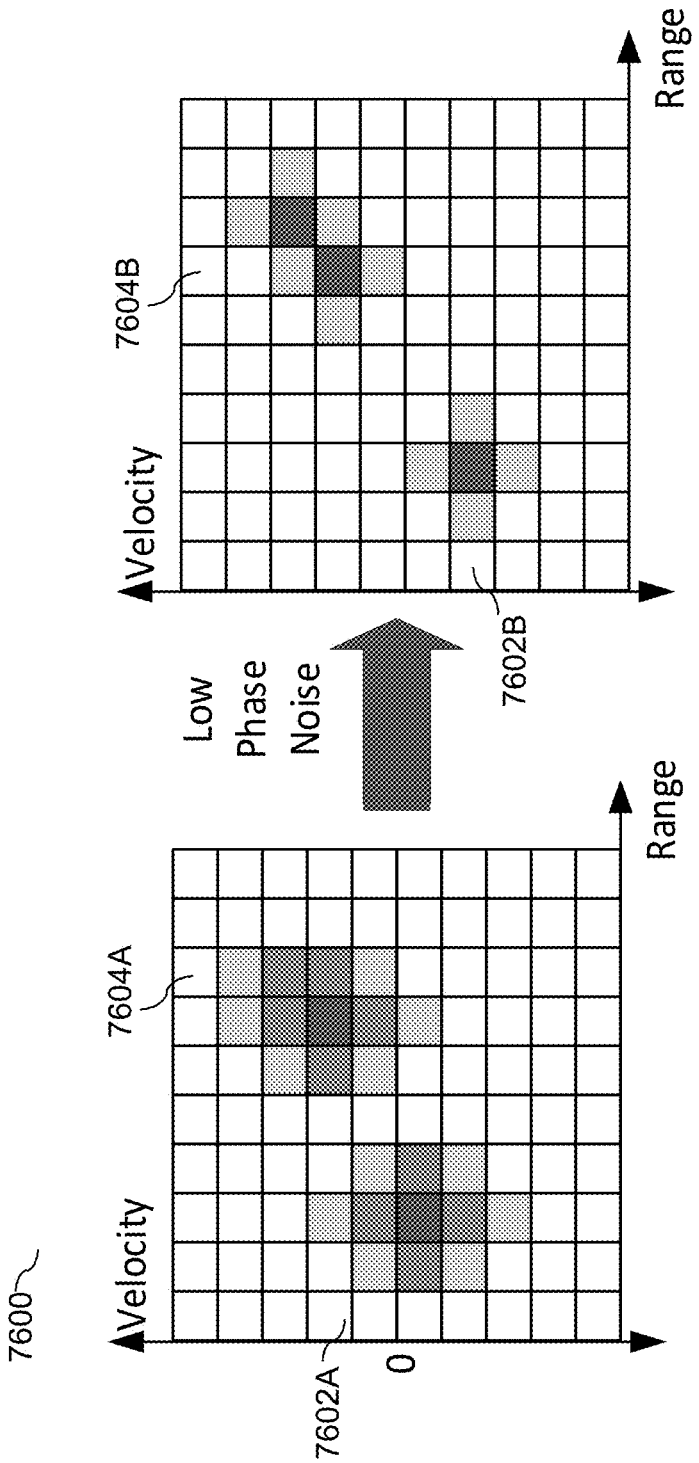
7600
Velocity
Range
7604A
7602A
0
Low
Phase
Noise
Velocity
Range
7604B
7602B

FIG. 76

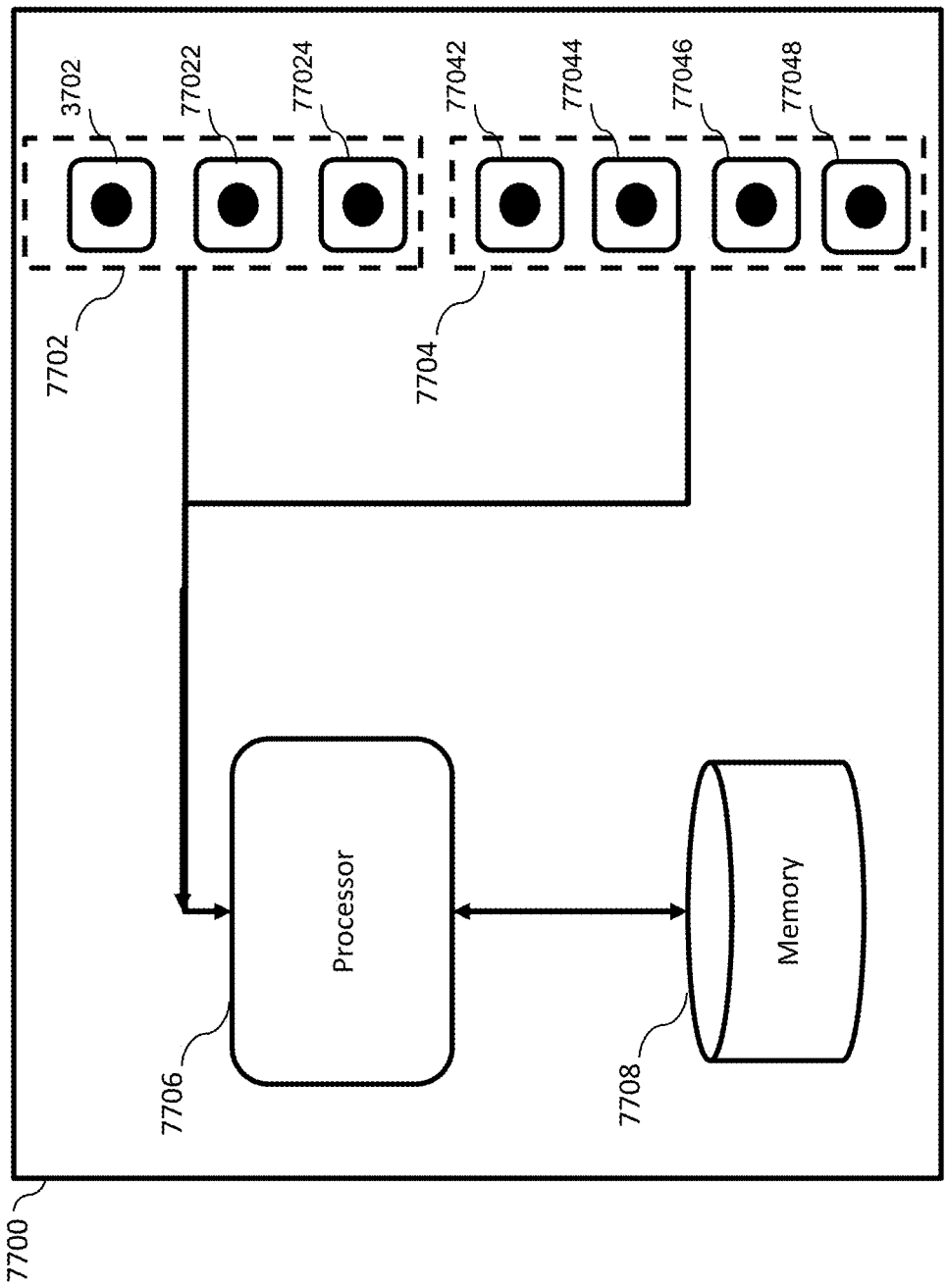
3702
77022
77024
77042
77044
77046
77048
7702
7704
Processor
Memory
7706
7708
7700

FIG. 77

RADAR TARGET DETECTION SYSTEM FOR AUTONOMOUS VEHICLES WITH ULTRA LOW PHASE NOISE FREQUENCY SYNTHESIZER

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation-in-part of U.S. application Ser. No. 15/995,557 filed on Jun. 1, 2018.

FIELD

Embodiments of the present disclosure are generally related to sensors for autonomous vehicles (for example, Self-Driving Cars) and in particular to systems that use ultra-low phase-noise frequency synthesizer for RADAR Sensor Applications for autonomous vehicles.

BACKGROUND

Autonomous vehicles are paving way for a new mode of transportation. Autonomous vehicles require minimum or no intervention from vehicle's driver. Generally, some autonomous vehicles need only an initial input from the driver, whereas some other designs of the autonomous vehicles are continuously under control of the driver. There are some autonomous vehicles that can be remotely controlled. For example, automatic parking in vehicles is an example of the autonomous vehicle in operation.

Autonomous vehicles face a dynamic environment that is the environment keeps changing every time. The autonomous vehicles need to keep a track of lane markings, road edges, track road curves, varying surfaces that may include flat surfaces, winding roads, hilly roads etc. Alongside, the autonomous vehicles also need to keep a check on objects that are both stationary or mobile like a tree or a human or an animal. Hence, the autonomous vehicles need to capture a huge amount of information that keeps on changing every time.

Therefore, to overcome and meet these challenges, autonomous vehicles are provided with a various set of sensors. These sensors help the vehicle to gather all around information and help in increasing the degree of autonomy of the vehicle. The various types of sensors currently being used in autonomous vehicles are LiDAR sensors, Ultrasonic sensors, Image sensors, Global Positioning System (GPS) sensors, Inertial Measurement Unit (IMU) sensors, dead reckoning sensors, Microbolo sensors, Speed sensors, Steering-angle sensors, Rotational speed sensors, Real-time Kinematics sensors, and RADAR sensors. Two of the most used sensors are LiDAR and RADAR sensors.

LiDAR sensors: LiDAR is a device that maps objects in 3-dimensional by bouncing laser beams off its real-world surroundings. LiDAR in automotive systems typically uses a 905 nm wavelength that can provide up to 200 m range in restricted FOVs (field of views). These sensors scan the environment, around the vehicle, with a non-visible laser beam. LiDAR sensor continually fires off beams of laser light, and then measures how long it takes for the light to return to the sensor. The laser beam generated is of low intensity and non-harmful. The beam visualizes objects and measures ranges to create a 3D image of the vehicle's surrounding environment. LiDAR sensors are very accurate and can gather information to even up to very close distances around the vehicle. However, LiDAR sensors are generally bulky, complex in design and expensive to use. The costs

can be between around $8,000 and even up to $100,000. Smaller and less expensive LiDAR sensors are starting to be in the market. LiDAR may also require complex computing of the data collected that also adds to the costs. Also, in general, LiDARs can capture data up to a distance of around 200 m.

It is to be noted that LiDAR requires optical filters to remove sensitivity to ambient light and to prevent spoofing from other LiDARs. Also, the laser technology used has to be "eye-safe". Recently there are efforts being made to replace mechanical scanning LiDAR, that physically rotates the laser and receiver assembly to collect data over an area that spans up to 360° with Solid State LiDAR (SSL). SSLs have no moving parts and are therefore more reliable especially in an automotive environment that requires long-term reliability. However, SSLs currently have lower field-of-view (FOV) coverage.

In current LiDAR sensor design coverage is also a problem in terms of sensor gap and overlap, since the LiDAR in autonomous vehicles has very limited redundancy sensors that can provide the level of imaging that a LiDAR provides under optimal conditions. LiDAR is also weather susceptible. It turns blind when it comes to imaging in adverse weather conditions. LiDAR has limitations of creating clear imaging in conditions of fog, rain, snow, direct sunlight, and darkness. Also, LiDAR cannot read letters on a signboard. This is so because the signboard is flat.

RADAR sensors: RADAR sensors basically send out electromagnetic waves. When these waves hit an obstacle, they get reflected. Thus, revealing how far away an object is and how fast is it moving.

RADAR sensors are very crucial in today's autonomous vehicle applications. They are required to be more accurate.

Automotive RADARs can be categorized into three types: long-range RADARs, medium range RADARs, and short-range RADARs. Long range RADARs are used for measuring the distance to and speed of other vehicles. Medium range RADARs are used for detecting objects within a wider field of view e.g. for cross traffic alert systems. Short range RADARs are used for sensing in the vicinity of the car, e.g. for parking aid or obstacle detection. Depending on the application, RADAR requirements differ. Short range applications require a steerable antenna with a large scanning angle, creating a wide field of view. Long range applications, on the other hand, require more directive antennas that provide a higher resolution within a more limited scanning range. Two different frequency bands are mainly used for automotive RADARs: the 24 GHz band and the 77 GHz band. The 77 GHz band offers higher performance, but it is also more challenging to implement since for example losses are much higher at these frequencies. The 24 GHz RADARs are easier to develop but are larger in size, making it difficult to integrate them in a vehicle. RADARs operating at 24 GHz require around three times larger antennas than RADARs operating at 77 GHz, to achieve the same performance. A 77 GHz RADAR would thus be much smaller resulting in easier integration and lower cost. Moving to higher frequencies enables RADARs with a better resolution. However, a major challenge posed is to develop steerable antennas for 77 GHz RADARs with high enough performance at a reasonable cost. In one embodiment of the invention different types of antenna and meta-material-based antennas that are less prone to phase noise disturbance will benefit from this invention.

Some Automotive RADAR systems use a pulse-Doppler approach, where the transmitter operates for a short period, known as the pulse repetition interval (PRI), then the system

switches to receive mode until the next transmit pulse. As the RADAR signal returns, the reflections are processed coherently to extract range and relative motion of detected objects. Another approach is to use Continuous Wave Frequency Modulation (CWFM) or Frequency Modulated Continuous Wave (FMCW). This approach uses a continuous carrier frequency that varies over time with a receiver constantly on. To prevent the transmit signal from leaking into the receiver, separate transmit and receive antennas are used.

Generally, there are three types of RADARs in use in autonomous vehicles. Short range RADAR, that helps in collision warning, and provide assisted parking support. Medium Range RADAR helps to watch corners of the vehicle, help in blind spot detection, lane detection and avoid side/corner collisions. Further, long-range RADARs help in adaptive cruise control functions and early collision detection functions.

RADAR signal processing also needs to be efficient. It needs to intelligently group the bouncing signals from the same object in the range. Otherwise, the RADAR signal processing will be overwhelmed with the amount of signal processing and may get confused. Grouping is made possible by use of Doppler shift of the signals bouncing off from the surfaces with a. velocity different from the observation domain. Thus, Doppler maps are created, that depict the range to object returns on one axis and extracted velocity of the targets on the other.

RADARs have also been used for identifying and classifying humans. RADARs are not efficient in performing the human identification; however, there have been techniques that are being used for human identification.

One of the techniques uses reflectivity of humans using an ultra-wideband RADAR. In this technique, the polarization of the reflected signal can be analyzed and can be determined that there are some frequencies where, in one polarization, there is maximum reflectivity and a minimum in the other. However, the polarized signal depends mainly on the shape, posture, and position of the person. Thus, making it a highly unreliable technique for classification.

Another technique used for human classification uses a dual-band frequency modulated continuous wave RADAR. In this technique, the difference in reflected signal from an object at different frequencies (commonly 10 Hz to 66 Hz) is compared. Through this comparison, the threshold for the ratio of the received intensity between two frequencies, above which detected objects can be classified as animated was established.

Some techniques utilized and analyzed Doppler spectrum of CW RADAR to obtain a Doppler or micro-Doppler Signature for a walking human. Whereas, some of the techniques used wavelet transform to extract the micro signatures created by human walking. The same techniques can be utilized for other human movement and gesture control.

Other techniques that should be mentioned here include the use of 2 or more different frequencies and multiple chirp types, These and the techniques above support the evaluation and recognition of the electromagnetic characteristics and properties of a human being or another targeted object. These techniques can be used for material detection and human classification. Also, the usage of multiple frequencies and chirp types provides information for micro-Doppler and radar signature evaluation and recognition.

The techniques mentioned are directed towards identification of a human and distinguish them from other walking objects like animals. However, these techniques can also be used to recognize animals.

RADAR sensors are low priced and provide as excellent sensors. RADARs also cost much less than LiDAR and may be procured within $150. These sensors work extremely accurately in bad weather conditions like fog, snow, dirt, etc. RADAR sensors use extremely simple circuitry and thus are smaller in size that makes them easy to be manufactured, installed and used. However, one of the major drawbacks of the RADAR sensors is that they give confusing results when multiple objects are within the range. They are not able to filter noise in such situations. Existing RADARs do not offer the necessary resolution to distinguish objects with sufficient reliability. One of the main problems faced is the separation of small and large objects that travel at the same distance and velocity in adjacent lanes, e.g. a motorcycle driving in the lane next to a truck.

Major factors affecting RADAR performance are described in the following paragraphs:

Transmitter Power and Antenna:

The maximum range of a RADAR system depends in large part on the average power of its transmitter and the physical size of its antenna. This is also called the power-aperture product. The antenna itself remains a challenge for autonomous vehicles and a lot is invested in various antenna developments. The invention described here can be used with a type of antenna including antennas based and made out of meta-materials. In fact, the synergy between a meta-material antenna and this invention would result in a very high performing radar sensor.

Receiver Noise:

The sensitivity of a RADAR receiver is determined by the unavoidable noise that appears at its input. At microwave RADAR frequencies, the noise that limits detectability is usually generated by the receiver itself (i.e., by the random motion of electrons at the input of the receiver) rather than by external noise that enters the receiver via the antenna.

Target Size:

The size of a target as "seen" by RADAR is not always related to the physical size of the object. The measure of the target size as observed by RADAR is called RADAR cross-section and is determined in units of area (square meters). It is possible for two targets with the same physical cross-sectional area to differ considerably in RADAR size or RADAR cross-section. For example, a flat plate 1 square meter in the area will produce a RADAR cross-section of about 1,000 square meters at a frequency of 3 GHz when viewed perpendicular to the surface. A cone-sphere (an object resembling an ice-cream cone) when viewed in the direction of the cone rather than the sphere could have a RADAR cross-section of about 0.001 square meters even though its projected area is also 1 square meter. Hence, this may cause calculation mistakes and may give the wrong estimation of the objects identified.

Clutter:

Echoes from environmental factors like land, rain, birds and other similar objects may cause a nuisance to detect objects. Clutter makes it difficult to identify objects and their properties to a considerable extent.

Interference:

Signals from nearby RADARs and other transmitters can be strong enough to enter a RADAR receiver and produce spurious responses. Interference is not as easily ignored by automatic detection and tracking systems. Hence, interference may further add to noise to the RADAR signals.

Phase-Noise:

Phase-noise is defined as the noise created by short term phase fluctuations that occur in a signal. The fluctuations display themselves in the frequency domain as sidebands which appear as a noise spectrum spreading out either side of the signal (Can be seen on FIG. **34**)

Comparison Between LiDAR and RADAR

As compared to LiDAR sensors, RADAR sensors provide more robust information to the vehicles. LiDAR sensors are generally mounted on top of the vehicle and are mechanically rotated to gather surrounding information. This rotational movement is prone to dysfunction. Whereas in case of RADAR, as they are solid state and have no moving parts hence have a minimal rate of failures.

Also, LiDAR sensors produce pulsed laser beams and hence are able to gather information only when the pulsed beam is generating the laser beams. RADAR sensors can generate continuous beams and hence provide continuous information.

Also, LiDAR sensors generate enormous and complex data for which complex computational modules are required to be used. For example, some types of LiDAR systems generate amounts of 1-Gb/s data that require a substantial amount of computation by strong computers to process such high amount of data in a timely manner. In some cases, these massive computations require additional computation and correlation of information from other sensors and sources of information. These increases cost overheads for vehicle manufacturers. Whereas, RADAR sensors only generate small fractions of data that are easy to compute.

LiDAR sensors are also sensitive to adverse weather conditions such as rain, fog, and snow while RADAR sensors are not prone to weather conditions. Though RADAR is not affected by darkness and it can work well in adverse weather conditions, it may lower its resolution.

RADAR signatures of a walking human being are a big problem. These signatures are not easily recognizable. Detection of human beings is a problem to which most of the computing algorithms do not have good solutions. There are various algorithms known as segmenting algorithms that do provide a certain level of the solution. The processing engine of an autonomous vehicle may take input from RADAR, LiDAR, Camera, Ultrasound and other multiple sensors to build an image of the surroundings of the vehicle.

Further, RADARs are generally used to detect receding and approaching objects. Use of RADARs helps to decelerate the vehicle in applicable situations and warn the driver.

Stationary RADAR sensors are also in use to monitor a predetermined space for e.g. railway crossings may be monitored using stationary RADARs. The usage includes identification of objects in such railway crossings. In such situations either a warning can be generated, or the train may be decelerated. However, to effectively use the stationary RADARs it is very important to be able to determine the size of the objects identified by the RADAR sensor. These RADARs may include height estimating systems for objects located in the range of such a RADAR. This needs to be accurate as even small amounts of deviations between the plane and vertical sensor axis can result in large errors in estimating the object's size.

However, RADAR sensors are challenged when dealing with slow-moving objects such as cars, bicycles, and pedestrians. Furthermore, these traditional RADAR systems, whether using a modulated or non-modulated signal, have difficulties identifying objects that are very close to each other since one of them will be obscured due to the phase-noise of the system. Also, the drawback of existing RADAR sensors is the impact on their accuracy due to the phase-noise of its frequency source, the synthesizer. RADAR sensors are not able to relay size and shape of objects as accurately as LiDAR. RADAR sensors might not be a stand-alone solution. They can be accompanied by ultrasonic sensors or cameras. Though, RADAR is excellent in finding things that are solid over long distances, but, it may be challenging to identify things that are in a short range.

Therefore, there is a need for an enhanced detection system capable of implementing artificial intelligence using various sensory fusion including a plurality of LiDAR, Camera, Ultrasound, and RADAR sensors for helping in making informed decisions based on surrounding information for semi or autonomous vehicles. Furthermore, the system should be capable to overcome the shortcomings of the existing systems and technologies.

SUMMARY

Some of the Benefits of the Invention:

The present invention emphasizes that by incorporating the ultra-low phase-noise synthesizer in an existing RADAR system, the performance of the RADAR system will be improved substantially in terms of target detection accuracy and resolution and because of this it can become the dominant sensor for the handling of autonomous cars. Herein, the Synthesizer drastically reduces the phase-noise of RADAR signals so that such RADAR sensor will be able to replace current sensor systems at very low cost and with reliability at all lighting and adverse weather conditions.

A system that utilizes an ultra-lowphase-noise synthesizer will be able to provide data to a processor that can determine the electromagnetic characteristics of an object with sufficient accuracy so that the system is able to determine if the object is a living object such as a human being or an animal or if it is inanimate. It will also be able to provide data that is accurate enough to differentiate between the material objects are made of such as differentiating between wood and stone for example. As an example, the data generated by the RADAR system could be used to identify and verify the presence of a human on the sidewalk about to cross the street or a bicycle rider at the side of the road.

Further as a derivative of the capability to determine the material an object is made of combined with the electromagnetic waves capability to penetrate through many materials an object detection system utilizing an ultra-lowphase-noise synthesizer will provide data that will enable a processing unit (such as a specialized processor of the object detection system) to find objects that are visually obscured by another object and determine the material of the obscured and obscuring object. Thus, the system may be able to find a human behind a billboard/bus station advertisement or wildlife behind a bush or determine that these are only 2 bushes (or non-animated objects) one behind the other.

Further, a Radar system that utilizes an ultra-low phase-noise synthesizer will also include the possibility to be implemented inside a vehicles cabin. In such an implementation the Radar system would be able to count passengers inside the vehicle and monitor their vital signs and even detect the eyelid movement of the driver to detect fatigue for instance. In addition, such a radar system could be used in an autonomous vehicle used for ride sharing to determine if anything has been forgotten inside the vehicle or if any type of dirt or litter has been left behind or if the vehicle has been soiled.

In addition, a Radar system that utilizes an ultra-low phase-noise synthesizer will benefit from improved capa-

bilities such as identification of small movements of an object through improved micro-doppler performance for example. That way such a radar system could identify small movements of limbs and gestures and other small details of the environment. This feature could, for example, be used in an embodiment to improve the prediction of human behavior.

Additionally, a RADAR system that utilizes an ultra-lowphase-noise synthesizer may be used as an imaging RADAR that can discover silhouettes and create a true 3-dimensional map of the surroundings of the vehicle including the mapping of the objects that are not visible with light. Such a RADAR System would also be able to utilize Synthetic Aperture Radar (SAR) technology, Interferometry and Polarimetry (or other SAR related technologies) to define the exact characteristics of an objects backscatter such as, but not limited to, Surface roughness, Geometric structure, Orientation and more. Further, an ultra-lowphase-noise RADAR system enables the determination of electrical characteristic such as, but not limited to, Dielectric constant, Moisture content, Conductivity and more. The data creation of electromagnetic characteristics can also be achieved by combining the ultra-lowphase-noise synthesizer of this invention and using 2 or more different frequencies and multiple chirp types.

According to an embodiment of the present disclosure an object detection system for autonomous vehicles is provided, The object detection system may include a RADAR unit coupled to at least one ultra-lowphase-noise frequency synthesizer, configured for detecting the presence of one or more objects in one or more directions, the RADAR unit comprising: a transmitter for transmitting at least one radio signal; and a receiver for receiving at least one radio signalreturned from one or more objects/targets. Further, the object detection system may include the at least one ultra-low phase-noise frequency synthesizer that may be utilized in conjunction with the RADAR unit, for refining both the transmitted and the received signals, and thus determining the phase-noise and maintaining the quality of the transmitted and the received radio signals, wherein the at least one ultra-low phase-noise frequency synthesizer comprises: (i) at least one clocking device configured to generate at least one first clock signal of at least one first clock frequency; (ii) at least one sampling Phase Locked Loop (PLL), wherein the at least one sampling PLL comprises: (a) at least one sampling phase detector configured to receive the at least one first clock signal and a single reference frequency to generate at least one first analog control voltage; and (b) at least one reference Voltage Controlled Oscillator (VCO) configured to receive the at least one analog control voltage to generate the single reference frequency; and (c) a Digital Phase/Frequency detector configured to receive the at least one first clock signal and a single reference frequency to generate at least a second analog control voltage; and (d) a two-way DC switch in communication with the Digital Phase/Frequency detector and the sampling phase detector; (iii) at least one first fixed frequency divider configured to receive the at least one reference frequency and to divide the at least one reference frequency by a first predefined factor to generate at least one clock signal for at least one high frequency low phase-noise Direct Digital Synthesizer (DDS) clock signal; (iv) at least one high-frequency low phase-noise DDS configured to receive the at least one DDS clock signal and to generate at least one second clock signal of at least one second clock frequency; and (v) at least one main Phase Locked Loop (PLL).

Hereinabove, the main PLL may include: (a) at least one high-frequency Digital Phase/Frequency detector configured to receive and compare the at least one second clock frequency and at least one feedback frequency to generate at least one second analog control voltage and at least one digital control voltage; (b) at least one main VCO configured to receive the at least one first analog control voltage or the at least one second analog control voltage and generate at least one output signal of at least one output frequency, wherein the at least one digital control voltage controls which of the at least one first analog control voltage or the at least one second analog control voltage is received by the at least one main VCO; (c) at least one down convert mixer configured to mix the at least one output frequency and the reference frequency to generate at least one intermediate frequency; and (d) at least one second fixed frequency divider configured to receive and divide the at least one intermediate frequency by a second predefined factor to generate the at least one feedback frequency.

Herein, the RADAR unit or units create a 3-dimensional RADAR image using one or more RADAR sensors and/or one or more frequencies. The transmitting RADAR may be at one location of the vehicle while the receiving unit is at another location. The RADAR sensors may utilize Synthetic aperture RADAR (SAR) technology to create the 3-dimensional image. The 3-dimensional image may include information about objects that are obscured by visible light. In an embodiment, Bi-static and multi-static may also involve one vehicle transmitting while one or more other vehicles receive the return signals.

Further, the data from the Radar unit comprising an ultra-lowphase-noise synthesizer can and should be used for improved compressed sensing, micro-Doppler classification, object classification by electromagnetic characteristics and radar-based mapping of cities, roads and other venues that can or are being mapped with visual sensors

Also, in an embodiment of the invention presented here, the system can use a type of antenna including antennas made out of meta-materials or other materials.

Herein, the radar unit determines a distance and a direction of each of one or more objects. Further, the radar unit determines one or more characteristics, of two close objects irrespective of the size of the one or more objects. Again further, the radar unit differentiates between two or more types of the objects when one object is visually obscuring another object. Additionally, the radar unit utilizes a modulated or non-modulated radio signal, to determine the presence of a slow-moving target despite the very small Doppler frequency shift. Also, the radar unit utilizes a modulated or non-modulated radio signal, to determine the presence of a close-range target despite the very short signal travel time.

Additionally, a vehicle with RADAR imaging capabilities may create contact with other vehicles that have that same feature. The group of 2 vehicles or more will have an identification scheme, or will set up one, so that every vehicle will be able to detect return signals from every other vehicle and thus combine a 3-dimensional map of the surroundings for immediate autonomous driving purposes and/or mapping or another purpose. This modus operandi should not be limited only to vehicles transmitting and receiving a Radar signal, the transmitter or receiver can also be stationary, such as a radar on a traffic light that warns vehicles about congestion at a crossing. Actions derived from that information might include slowing down or having the GPS recalculate the route to avoid congestion.

The object detection system may further include at least one additional sensor system, available on the autonomous

vehicle, or a database connection in conjunction with the RADAR unit. The combined object detection and/or classification and imaging system may be used as real-time sensors and/or as (real-time) mapping device for single or multiple vehicles use through a direct vehicle-to-vehicle (V2V) or other connectivity solution

Further, considering the example of the pedestrian on the sidewalk or the bicycle rider at the side of the road once the RADAR unit has detected something of interest this can be used in conjunction with other sensors, a LiDAR device for instance. In such a case the visible field for the LiDAR could be reduced to 1/100 of its usual Field of View (FOV) and the elevation angle by another 1/10 to 1/100 of its original FOV reducing the computation needed for the LiDAR by 1/1000 to 1/10000.

Further, the at least one ultra-low phase-noise frequency synthesizer further comprises at least one fixed frequency multiplier configured to receive and multiply the at least one output signal generated by the at least one main PLL by a predefined factor to generate at least one final output signal of at least one final output frequency. The at least one ultra-low phase-noise frequency synthesizer is implemented on the same electronic circuitry or on a separate electronic circuitry. Further, the ultra-low phase-noise frequency synthesizer may be used to generate the up or down converting the signal of the RADAR unit.

Further, according to another embodiment of the present disclosure, a method for autonomous vehicles is disclosed. The method may include (but is not limited to): detecting a presence of one or more objects in one or more directions by a RADAR unit. Herein, the RADAR unit comprising: a transmitter for transmitting at least one radio signal to the one or more objects; and a receiver for receiving the at least one radio signal returned from the one or more objects. Further, the method may include performing, by at least one ultra-low phase-noise frequency synthesizer for refining the transmitted signal and not adding phase-noise to the received signals, and thereby determining a phase-noise and maintaining the quality of the transmitted and the received radio signals.

Herein, the method may further include various steps such as receiving and multiplying, by the ultra-low phase-noise frequency synthesizer, the at least one output signal by a predefined factor to generate at least one final output signal of at least one final output frequency. Further, the method may generate the up converting or down converting the signal of the RADAR unit. Furthermore, the method may determine the presence of a slow-moving target despite the very small Doppler frequency shift. Again further, the method may include determining the presence of a close-range target despite the very short signal travel time. Additionally, the method may determine a distance and a direction of each of the one or more objects. Furthermore, the method may determine a type of material an object is made up of. Also, the method may include a step of activating one or more additional sensors for operation thereof in conjunction with the RADAR unit. The method may determine characteristics of two close objects irrespective of the size of the objects. Further, the method may differentiate between two or more types of the objects when one object is visually obscuring another object. Further, the method may improve techniques such as compressed sensing, micro-Doppler classification and object classification according to its electromagnetic characteristics.

According to an embodiment of the present disclosure, a system is a detection system that comprises a RADAR unit, communicably coupled to at least one ultra-low phase-noise frequency synthesizer, is provided. The RADAR unit configured for detecting the presence of one or more objects in one or more directions. Herein, the RADAR unit comprising: a transmitter for transmitting at least one radio signal; and a receiver for receiving at least one radio signal returned from one or more objects/targets. Further, the detection system may include at least one ultra-low phase-noise frequency synthesizer that may be configured for refining the returning the at least one radio signal to reduce phase-noise therefrom.

Herein, the system includes at least one ultra-low phase-noise frequency synthesizer configured to determine phase-noise and quality of the transmitted and the received at least one radio signal. The ultra-lowphase-noise frequency synthesizer is a critical part of a System, regardless of how it is implemented. The ultra-lowphase-noise frequency synthesizer comprises one main PLL (Phase Lock Loop) and one reference sampling PLL. The main PLL comprises one high-frequency DDS (Direct Digital Synthesizer), one Digital Phase Frequency Detector, one main VCO (Voltage Controlled Oscillator), one internal frequency divider, one output frequency divider or multiplier and one down convert mixer. The reference sampling PLL comprises one reference clock, one sampling phase detector, one digital phase/frequency detector and one reference VCO. This embodiment provides a vast and critical improvement in the overall system output phase-noise. The synthesizer design is based on the following technical approaches—a) using of dual loop approach to reducing frequency multiplication number, b) using of sampling PLL as the reference PLL to make its noise contribution negligible, c) using of DDS to provide high-frequency input to the main PLL and d) using of high-frequency Digital Phase Frequency Detector in the main PLL.

In an additional embodiment of present disclosure, the system includes at least one ultra-low phase-noise frequency synthesizer configured to determine phase-noise and quality of the transmitted and the received at least one radio signal. The ultra-low phase-noise frequency synthesizer comprises one main PLL (Phase Lock Loop) and one reference sampling PLL. The main PLL further comprises one Fractional-N Synthesizer chip, one primary VCO (Voltage Controlled Oscillator) and one down convert mixer. The Fractional-N Synthesizer chip includes one Digital Phase Detector and one software controllable variable frequency divider. The reference sampling PLL comprises one reference clock, one sampling phase detector, one digital phase/frequency detector and one reference VCO. This embodiment provides multiple improvements in system output which are based on the following technical approaches—a) using of dual loop approach to reducing frequency multiplication number, b) using of sampling PLL to make its noise contribution negligible, and c) using of a high-frequency Fractional-N Synthesizer chip in the main PLL.

In an additional embodiment of present disclosure, the system includes at least one ultra-low phase-noise frequency synthesizer configured to determine phase-noise and quality of the transmitted and the received at least one radio signal. The ultra-lowphase-noise frequency synthesizer comprises one sampling PLL. The sampling PLL comprises one reference clock, one sampling phase detector, one digital phase/frequency detector and one VCO.

According to an embodiment of the present disclosure, a detection system comprising a RADAR unit and an ultra-lowphase-noise frequency synthesizer is provided. The system is made up of System on Chip (SoC) module. The RADAR unit configured for detecting the presence or imag-

ing of one or more objects in one or more directions. The RADAR unit comprising: a transmitter for transmitting at least one radio signal; and a receiver for receiving the at least one radio signalreturned from the one or more objects/targets. In an embodiment, the Transmit and receive signal frequencies might be equal. For example, if there is no Doppler effect, the signal frequencies may be equal. In an embodiment, the transmit and receive frequencies might also be different, for example in cases where the Doppler effect is present. The ultra-lowphase-noise frequency synthesizer comprises one main PLL (Phase Lock Loop) and one reference sampling PLL. The main PLL further comprises one Fractional-N Synthesizer chip, one primary VCO (Voltage Controlled Oscillator) and one down convert mixer. The Fractional-N Synthesizer chip includes one Digital Phase Detector and one software controllable variable frequency divider. The reference sampling PLL comprises one sampling PLL, and one reference VCO. This embodiment provides multiple improvements in system output which are based on the following technical approaches—a) using of dual loop approach to reducing frequency multiplication number, b) using of sampling PLL to make its noise contribution negligible, and c) using of a high-frequency Fractional-N Synthesizer chip in the main PLL.

In an additional embodiment of the present disclosure, a vehicle having a detection system is disclosed. The detection system may be implemented for detecting information corresponding to one or more objects, the detection unit comprising: a RADAR unit for transmitting radio signals and further for receiving the returned radio signal(s) from one or more objects/targets; and at least one ultra-low phase-noise frequency synthesizer for refining the returned signals to reduce the effect of phase-noise in the returned radio signals. Further, the detection unit comprises a processor for processing the refined signals to determine one or more characteristics corresponding to the one or more objects, the processor determining one or more actions based on one or more factors and the one or more characteristics corresponding to the one or more objects. The processor further may determine one or more actions being adaptable by the vehicle based on one or more characteristics that may originate from the RADAR system and/or in conjunction with information originated from another sensor. The vehicle further includes one or more components communicably coupled to the processor for performing the determined one or more actions.

The detection system may further include a memory for storing information and characteristics corresponding to the one or more objects, and actions performed by the vehicle.

Hereinabove, the at least one ultra-low phase-noise frequency synthesizer may be implemented in a manner as described further in the detailed description of this disclosure. Further, the RADAR unit comprises at least one of: traditional single antenna RADAR, dual or multi-antenna RADAR, synthetic aperture RADAR, and one or more other RADARs. Further, in an embodiment, the processor may determine phase shift in frequencies of the transmitted radio signals and the returned radio signals. Such phase shift (difference in phase-noise frequency) may further be analyzed in light of a frequency of the refined radio signal to self-evaluate overall performance of the detection system (or specific performance of the ultra-low phase-noise frequency synthesizer).

The preceding is a simplified summary to provide an understanding of some aspects of embodiments of the present disclosure. This summary is neither an extensive nor exhaustive overview of the present disclosure and its various embodiments. The summary presents selected concepts of the embodiments of the present disclosure in a simplified form as an introduction to the more detailed description presented below. As will be appreciated, other embodiments of the present disclosure are possible utilizing, alone or in combination, one or more of the features set forth above or described in detail below.

Current Radar sensors that reside in existing vehicles provide coarse information about the vehicles surroundings. This invention discloses a system that utilizes a new and innovative frequency generation mechanism (Synthesizer) to improve the Radar sensor performance significantly. The spectral purity (Phase Noise) of a local oscillator (LO) of a radar system is usually perceived as a parameter that cannot be manipulated or improved. In addition, many radar systems in use today implement a single LO that serves the transmit and receive paths so that the phase-noise close to the carrier frequency is assumed to be cancelled by self-correlation. This assumption originates because near field echoes, that have a very short travel time, will find the LO approximately in the same state as it was during transmission. As a result, the phase-noise is considered partially cancelled out for low frequency deltas around the LO.

Doppler Shift:

Single LO Radar systems are common in Assisted driving systems and autonomous vehicles which turns the emphasis on the statement above to the phrase "the phase-noise is partially cancelled". The fact that the phase-noise partially cancelled while the signal processing of the Radar systems practically assumes that the phase-noise is completely canceled creates a few disadvantages since these Radars rely heavily on the doppler principle, i.e.: based on frequency shifts. When utilizing the Doppler principal every stationary object theoretically creates a reflected signal that lands exactly on DC after down-conversion. In the presence of phase-noise, stationary objects have some velocity around DC due to that phase-noise. In this specification we will call that "Doppler Jitter" which is generally caused by clutter. In order to reduce the effect of clutter the DC portion of the signal is disregarded for signal processing purposes.

This in turn causes one of 2 issues:

1. 1st Option—Some clutter still remains because of the doppler jitter, and then slow-moving objects such as walking human beings are obscured by the clutter
2. 2nd Option—The Signal processing removes some bandwidth around DC, and then slow-moving objects are completely disregarded.

Both of the options above bare disadvantages which are further exacerbated as follows:

1. The Radar Cross Section (RCS) of a human is significantly smaller of a car. In some cases, a human's radar cross section is about 10 to 100 times smaller that of a car or approximately in the order 0 dBsm. On the contrary the RCS of a small car can be between 10 to 20 dBsm, depending on the side the Radar hits the car.
2. The slower the vehicle that carries the radar sensor moves the smaller the doppler shift for slow moving objects—a scenario that is common in urban areas where cars and humans coexist.
3. In addition to 2 above, the urban environment is also challenging because the distance between vehicle and other surrounding objects may be very short so that the return signal will suffer from one of the 2 issues mentioned above.
4. Micro Doppler—the movement of limbs creates very small frequency shifts with very small return signal amplitudes and often times in the opposite or different

direction of the generic movement of the human, this again brings us back to the 2 unwanted options in the section above.

To summarize the disadvantages mentioned above with respect to the Doppler frequency shift and phase noise: it is very hard to detect objects that move slow and have a small Radar Cross Section (RCS), such as pedestrians or bicyclists.

On the contrary, with ultra-low phase-noise, it is much simpler to identify and classify objects that move slow and have a small Radar Cross Section (RCS), such as pedestrians or bicyclists. Further it is easier to compute the processing their velocity and location even if the distance is small. Further, Ultra-Low Phase-Noise opens an entire domain of micro-Doppler signal processing.

Phase Noise Amplification:

Radar System uses amplifiers in the transmit, receive and LO distribution paths. All of these amplifiers suffer from a non-linear deficiency usually referred to as "1/f Noise". Meaning that the amplifier adds more noise closer to the signal it amplifies that further away from it. Vehicle mounted Radar systems usually use a form of Frequency Modulated Continuous Wave (FMCW) which originate from the LO and already carry noise with them in the form of Phase Noise. When these signals travel through an amplifier, the phase-noise is essentially amplified according to 1/f distance from the CW frequency. When implementing the disclosed radar with ultra-low phase-noise synthesizer this kind of spectral contamination is reduced by 100-1000 times.

Pulse Compression

The following section discusses pulse compression, which is a signal processing method very often utilized together with FMCW. During the pulse compression signal creation, the phase-noise of the signal shows as sidelobes or elevated noise around the processed radar echo which essentially triggers **2** ripple effects:

1. Reduced Signal to Noise Ratio diminishes the capability of object classification (especially objects with a small RCS)
2. Reduced Signal to Noise Ratio causes worse Radar sensitivity and results in less range

Additional Advantages of Ultra-Low Phase-Noise

Many Radar systems implement beam forming mechanisms. Whether these mechanisms rely on phase shifting or electronic beamforming, the phase-noise in the system will always add an error in the actual direction of the beam, therefore it is intuitively understandable that with lower phase-noise better angular accuracy of the beam can be achieved.

Although not very advanced in the automotive world, another item that should be mentioned is Synthetic Aperture Radar (SAR) imaging. SAR imaging is in use by aircrafts and satellites for many years and the importance of phase-noise is well understood for the different methods of SAR imaging.

Furthermore, different objects may be consistent or are made out of different materials that have different electromagnetic characteristics, and therefore they will have a return signal that are not only specific to the object's velocity, size and location, but also specific to its electromagnetic characteristics.

Sensory Fusion:

Ultra-low phase-noise based radar may experience and "see" the environment in different way than camera, LiDAR, ultrasonic sensor or other sensors. In this way the Ultra-low phase-noise based radar "see" non-visual information that is not visible to other sensors. The detection range of such radar can be much larger than other sensors and specifically with adverse weather and lighting. Different objects return different radar signatures that can be used for classification and detection of such object using Artificial Intelligence (AI) and Machine Learning (ML).

In an embodiment of this invention the ultra-low phase noise Radar may start the detection, classification and perception process at a greater range than traditional Radars, thus it may provide an early warning for other sensors and ample time for a processing unit that may process the data, poll data from sensors, run AI/ML algorithms and perform decision making processes.

Ample time of advanced notice about the potential and probability of an object can be fused with other sensors for early processing and focusing to the area and direction of the suspected object. Such object classification may include the statistical probability and likelihood for classification of the detected object in a range. For example, classification probability of P_1% detection in range R_1, P_2% in range R_2, and P_3% in range R_3. In case of detection and classification at a substantially larger range by the radar, the data can be fused and computed as an input or trigger for different sensors.

Some Benefits:

The implementation of ultra-low phase-noise synthesizers in Radar systems has been discussed in detail for the Doppler phenomenon, 1/f noise and pulse compression. Further, beamforming, SAR imaging and material recognition have been mentioned at a high level. Following primary and secondary conclusions can be derived:

1. Primary advantages for the implementation of ultra-low phase-noise synthesizers in Radar systems are:
   a. Much better accuracy in the Doppler and micro-Doppler domains
   b. Signal processing improvements that have an impact on the accuracy and the range of the Radar sensor
   c. Improved SAR imaging and more accurate usage of beamforming mechanisms
2. Secondary advantages for the implementation of ultra-low phase-noise synthesizers in Radar systems are:
   a. The sensory fusion mechanisms will have more accurate Radar sensor data at their disposal and new information vectors that were previously non-existing.
   b. Since Radar is not a "visual sensor" per se, true sensory fusion is made possible.
   c. A single radar sensor can create multiple information vectors about a single object. This satisfies the most important objective of identifying living objects such as a human or an animal.

In one embodiment of the present invention, a system for detecting the surrounding environment of a vehicle is disclosed. The system may include, but is not limited to, at least first sensor and a processing unit. The at least first sensor may be configured to obtain data. The at least first sensor may include (but is not limited to) a transmitter for transmitting at least one radio signal to the one or more objects within the surrounding environment. Further, the at least one sensor may include a receiver for receiving the at least one radio signal returned from the one or more objects. Furthermore, the at least one sensor may include at least one ultra-low phase noise frequency synthesizer configured to determine phase noise and quality of the transmitted and the received at least one radio signal, wherein the at least one ultra-low phase noise frequency synthesizer comprises at least one sampling Phase Locked Loop (PLL) and at least one main PLL, said Sampling PLL comprises a sampling phase detector and said main PLL comprises a high fre-

quency digital phase/frequency detector. Further, the processing unit coupled to the at least first sensor configured to: gather, electro-magnetic information about the one or more objects; classify or recognize each of the one or more objects by analyzing the data, wherein the classification or recognition is based on a unique signature obtained from each of the one or more objects; generate an electromagnetic map of the surrounding environment by utilizing unique signatures of the one or more objects; and combine the electromagnetic map with a geographical map or physical map.

Hereinabove, the at least first sensor is a RADAR sensor. Further, the data includes information about the electromagnetic properties and characteristics about the object of interest or the surroundings of the vehicle. The data may include (but is not limited to) shape, silhouette, doppler or micro doppler information. Further, the data includes depth, dimensions, direction, height, distance and placement of the object of interest with respect to the vehicle. Furthermore, the classification type of the one or more objects includes living or non-living thing, stationary or moving object, animal or human, standing or mobile human, metal, wood, or concrete.

In another embodiment of the invention, a method for detecting the surrounding environment of a vehicle is disclosed. The method may include (but not limited to) utilizing at least a first sensor to obtain a data. The at least first sensor being utilized for: transmitting, by a transmitter, at least one radio signal to the one or more objects within the surrounding environment; receiving, by a receiver, the at least one radio signal returned from the one or more objects; and determining phase noise and quality of the transmitted and the received at least one radio signal by at least one ultra-low phase noise frequency synthesizer, wherein the at least one ultra-low phase noise frequency synthesizer comprises at least one sampling Phase Locked Loop (PLL) and at least one main PLL, said Sampling PLL comprises a sampling phase detector and said main PLL comprises a high frequency digital phase/frequency detector. The method may further include gathering, electro-magnetic information about the one or more objects; classifying or recognize each of the one or more objects by analyzing the data, wherein the classification or recognition is based on a unique signature obtained from each of the one or more objects; generating an electromagnetic map of the surrounding environment by utilizing unique signatures of the one or more objects; and combining the electromagnetic map with a geographical map or physical map.

Hereinabove, the method may further include recognizing the object on interest after classifying, wherein the classification of the object of interest includes living or non-living thing, stationary or moving object, animal or human, standing or mobile human, metallic, wooden, or concrete objects.

BRIEF DESCRIPTION OF THE DRAWINGS

The above and still further features and advantages of embodiments of the present invention will become apparent upon consideration of the following detailed description of embodiments thereof, especially when taken in conjunction with the accompanying drawings, and wherein:

FIG. **1** illustrates a general block diagram of a negative feedback system;

FIG. **2** illustrates a general block diagram of a standard Phase Lock Loop (PLL);

FIG. **3** illustrates a simplified drawing of a digital phase/frequency detector;

FIG. **4** illustrates an example of an active filter as applied to a general PLL;

FIG. **5** illustrates the principle of the sample-and-hold mechanism;

FIG. **6** illustrates a schematic of the step recovery diode as comb generator feeding the dual Schottky diode that acts as phase detector;

FIG. **7** illustrates a complete example schematic of the comb generator and sampling phase detector with RF preamplifier and two DC buffers following the phase detector;

FIG. **8** illustrates a phase-noise plot of an example free running Voltage Control Oscillator (VCO) in the frequency domain (spectrum analyzer), without being locked in a PLL;

FIG. **9** illustrates a phase-noise plot of an example Voltage Control Oscillator (VCO) in the frequency domain (spectrum analyzer), compensated by being locked in a PLL;

FIG. **10** illustrates two plots: (a) a simulation of phase-noise of an example PLL, and (b) is an actual measurement;

FIG. **11** illustrates a phase-noise plot of a closed loop PLL, showing clearly the effect of the phase detector multiplication number 20*LOG(N) within loop bandwidth;

FIG. **12** illustrates a plot of measurement in terms of phase-noise in 1 Hz bandwidth at aΔf offset frequency from the carrier;

FIG. **13** illustrates a general block diagram of an example dual loop PLL;

FIG. **14** illustrates a general block diagram of an example dual sampling PLL;

FIG. **15** illustrates how impulse or "comb" generator changes a wave shape of a signal from a sine wave to pulses;

FIG. **16** illustrates an example output of a comb generator in the frequency domain;

FIG. **17** illustrates a block diagram of an ultra-low phase-noise frequency synthesizer as suggested in a first embodiment;

FIG. **18** illustrates a block diagram of an ultra-low phase-noise frequency synthesizer as suggested in a second embodiment;

FIG. **19** illustrates a block diagram of the sampling PLL system;

FIG. **20** illustrates a phase-noise simulation plot contributed by a DDS chip in accordance with the first embodiment of the present disclosure;

FIG. **21** illustrates a phase-noise simulation plot contributed by the main PLL in accordance with the first embodiment of the present disclosure;

FIG. **22** illustrates a phase-noise simulation plot contributed by a reference sampling PLL having the TCXO clock (or other reference Clock) generating input frequencies of 100 MHz in accordance with the first embodiment of the present disclosure;

FIG. **23** illustrates a phase-noise simulation plot contributed by a reference sampling PLL having the TCXO clock (or other reference Clock) generating input frequencies of 250 MHz in accordance with the first embodiment of the present disclosure;

FIG. **24** illustrates a phase-noise simulation plot contributed by the main PLL in accordance with the second embodiment of the present disclosure;

FIG. **25** illustrates a phase-noise simulation plot contributed by a reference sampling PLL having the TCXO clock (or other reference Clock) generating input frequencies of 100 MHz in accordance with the second embodiment of the present disclosure;

FIG. **26** illustrates a phase-noise simulation plot contributed by a reference sampling PLL having the TCXO clock

(or other reference Clock) generating input frequencies of 250 MHz in accordance with the second embodiment of the present disclosure;

FIG. **27** illustrates a flowchart depicting the operational method steps of the first embodiment;

FIG. **28** illustrates a flowchart depicting the operational method steps of the second embodiment;

FIG. **29** illustrates a flowchart depicting the operational method steps of the sampling PLL;

FIGS. **30**A, **30**B, **31-36** correspond to prior arts and existing technologies;

FIG. **37** illustrates a detection system, in accordance with various embodiments of the present invention;

FIG. **38** illustrates an exemplary vehicle implementing detection system, in accordance with an embodiment of the present invention;

FIG. **39** illustrates a block diagram of an exemplary RADAR, in accordance with an embodiment of the invention;

FIG. **40**A illustrates an exemplary 3-dimensional map generation using the RADAR, in accordance with an embodiment of the invention;

FIG. **40**B illustrates another exemplary 3-dimensional map generation using the RADAR, in accordance with an embodiment of the invention;

FIG. **41** illustrates another example of 3-dimensional mapping using the RADAR, in accordance with an embodiment of the invention;

FIG. **42** illustrates a flowchart depicting an overall method, in accordance with an embodiment of the invention;

FIG. **43** illustrates a flowchart depicting the operational method steps of the first embodiment, in accordance with another embodiment of the invention;

FIG. **44** illustrates a line diagram depicting an improvement in RADAR signals, in accordance with the present invention;

FIG. **45** illustrates a line diagram depicting object identification, in accordance with an embodiment of the present invention;

FIG. **46**(FIG. **46**A and FIG. **46**B) illustrates a line diagram depicting identification of obscured objects, in accordance with an embodiment of the present invention;

FIG. **47** illustrates a line diagram depicting identification of road and pavement, in accordance with an embodiment of the present invention;

FIG. **48** illustrates a block diagram of a processor, in accordance with an embodiment of the present invention;

FIG. **49** illustrates a flowchart of a method for identifying live objects using the detection system, in accordance with an embodiment of the invention;

FIG. **50** illustrates a block diagram of a detection system, in accordance with an embodiment of the invention;

FIG. **51** illustrates a method for detecting and imaging objects for a vehicle, in accordance with an embodiment of the invention;

FIG. **52** illustrates a block diagram of a processor and its various internal components to perform detection of objects, in accordance with an embodiment of the invention;

FIG. **53** illustrates a flowchart for a method of identification of a potential threat object, in accordance with an embodiment of the invention;

FIG. **54**, illustrates a block diagram displaying advantages of using selective use of the at least second sensor, in accordance with an embodiment of the invention;

FIG. **55**, illustrates a block diagram displaying advantages of using selective use of the at least second sensor, in accordance with an embodiment of the invention;

FIG. **56** illustrates a flowchart for a method for recognition of a living body, in accordance with an embodiment of the invention;

FIG. **57** illustrates an exemplary method flow diagram for detecting and imaging objects for a vehicle, in accordance with an embodiment of the invention;

FIG. **58** illustrates a block diagram of a detection system for detecting surrounding environment, in accordance with an embodiment of the invention;

FIG. **59** illustrates a block diagram of the processor and its various internal components to perform detection of objects, according to an embodiment of the invention;

FIG. **60** illustrates a block diagram of system depicting formation of RADAR maps, in accordance with an embodiment of the present invention;

FIG. **61** illustrates a block diagram of a detection system for RADAR maps generation, in accordance with an embodiment of the invention;

FIG. **62** illustrates a block diagram of the processor and its various internal components to perform detection of objects, according to an embodiment of the invention;

FIG. **63** illustrates a flow chart illustrating a method for RADAR map generation, in accordance with an embodiment of the invention;

FIG. **64** illustrates an exemplary embodiment of a collective mapping system to build a collective map of the surrounding environment, in accordance with an embodiment of the invention;

FIG. **65**A illustrates a block diagram of the processor and its internal processing modules, according to one embodiment of the invention;

FIG. **65**B illustrates a block diagram of the processor and its internal processing modules, according to another embodiment of the invention;

FIG. **66** illustrates a flow chart representing a method performed by the system for creating collective map data, in accordance with an embodiment of the invention;

FIG. **67**A illustrates a block diagram of a surrounding environment along with various objects within the surrounding environment, in accordance with an embodiment of the invention;

FIG. **67**B illustrates localization of the vehicle while traversing the environment, in accordance with an embodiment of the invention;

FIG. **68** illustrates a flow chart depicting a method for generation of navigational maps, in accordance with an embodiment of the invention;

FIG. **69**, illustrates a Radar upchirp and downchirp without phase-noise and the effect on the beat frequency;

FIG. **70**, illustrates a Radar upchirp and downchirp with phase-noise and the effect on the beat frequency;

FIG. **71**, illustrates upchirps and downchirps without phase-noise when two "real objects" are present and the "ghost objects" created by the system;

FIG. **72**, illustrates upchirps and downchirps, with phase when two "real objects" are present and the "ghost objects" that are created by the system and their data blurred by phase-noise;

FIG. **73**, illustrates the Fourier transform of the beat frequency without the presence of phase-noise;

FIG. **74**, illustrates the Fourier transform of the beat frequency with the presence of phase-noise;

FIG. **75**, illustrates the method of detecting a stationary object using the properties of phase-noise;

FIG. **76** illustrates a common analysis of Radar signals on 2 dimensional FFT grid, in accordance with an embodiment of the invention; and

FIG. **77** illustrates an exemplary embodiment of a long range, ample time advanced notice detection and classification system, in accordance with an embodiment of the invention.

To facilitate understanding, like reference numerals have been used, where possible, to designate like elements common to the figures.

DETAILED DESCRIPTION

As used throughout this application, the word "may" be used in a permissive sense (i.e., meaning having the potential to), rather than the mandatory sense (i.e., meaning must). Similarly, the words "include", "including", and "includes" mean including but not limited to.

The phrases "at least one", "one or more", and "and/or" are open-ended expressions that are both conjunctive and disjunctive in operation. For example, each of the expressions "at least one of A, B and C", "at least one of A, B, or C", "one or more of A, B, and C", "one or more of A, B, or C" and "A, B, and/or C" means A alone, B alone, C alone, A and B together, A and C together, B and C together, or A, B and C together.

The term "a" or "an" entity refers to one or more of that entity. As such, the terms "a" (or "an"), "one or more" and "at least one" can be used interchangeably herein. It is also to be noted that the terms "comprising", "including", and "having" can be used interchangeably.

The term "automatic" and variations thereof, as used herein, refers to a process or operation done without material human input when the process or operation is performed. However, a processor an operation can be automatic, even though the performance of the processor operation uses the material or immaterial human input if the input is received before performance of the processor operation. Human input is deemed to be material if such input influences how the process or operation will be performed. Human input that consents to the performance of the processor operation is not deemed to be "material".

The present disclosure includes implementation of an upgraded RADAR unit by incorporating an ultra-lowphase-noise frequency synthesizer to make the RADAR functioning effectively by transmitting radio signals with much lower phase-noise than what is found in traditional RADAR systems on the transmit side. On the receive side of the RADAR system, the ultra-lowphase-noise synthesizer adds only a very small amount of phase-noise to the signal. More specifically, in an embodiment, the upgraded RADAR unit generates a very low amount of phase-noise and thus minimizing the impact of phase-noise on the transmitted and the received signal. The RADAR unit may include a Synthetic Aperture RADAR (SAR), or another kind of RADAR, for determining information corresponding to targets. Further, the present disclosure may utilize modulated signal such as Frequency Modulated Continuous Wave (FMCW) of a type or other modulated signal for the RADAR Unit. As mentioned above FMCW based RADAR is advantageous in terms of power saving Further, in FMCW based RADAR unit, various factors such as distance and velocities may be determined based on frequency differences from the instantaneous transmitted signal rather than travel time. In most cases, FMCW RADAR signals are processed with the help of FFT utilizing signal processing windows and pulse compression algorithms. While these methods are good, the phase-noise of the system still remains important since it is a statistical phenomenon that may be measured and calculated as an average, but instantaneous value thereof cannot be determined, thus it cannot be mitigated easily with existing algorithms. However, its influence on system performance will drastically be reduced with the collaboration of ultra-lowphase-noise frequency synthesizer. As a result, the overall system capability of accuracy and target detection will be vastly improved. Further, once distances, return phases and velocities can be determined with high accuracy, the data can be used to put together an accurate 3-dimensional image of the surroundings.

RADAR sensors are generally placed in the middle of the front bumper of a vehicle. There can be several RADAR units on the front and back bumper of a vehicle. Some of them are operable in the 24 Ghz band and some of them are in the 77 GHz band. Each of them may have different characteristics. Together these multi-frequency RADARs can provide more information. In addition, multiple RADARs can also work as SAR, that helps in getting a better image.

The placement of the RADARs on the vehicle enables features like forward-collision, collision-warning etc. As described earlier, the RADAR sensors utilize a transmitter to send short pulses of electromagnetic radiation. In some models, the transmitter is turned off after transmission and receiver listens for reflected pulses bouncing off from objects. However, if the transmitter and the receiver are separate then there is no need to switch off the transmitter between pulses. Integration of the RADAR sensors into the bumper needs to be performed carefully. Otherwise, there might be interference and accuracy problems. Therefore, the signals from the RADAR sensor should be of high quality and relatively constant across azimuth of the sensor while minimizing the wasted energy and delivering to undesired directions or being bounced back from bumper itself.

For perfect working of the RADAR sensor, while being placed in the bumper, electrical properties of the bracket where it is to be fitted and the fascia materials are taken to simulate RADAR working. The simulations may be done utilizing waveguide or quasi-optical properties. The measured electrical properties may include dielectric constant and loss of tangent of the fascia, bracket of the RADAR sensor and the paint layer.

RADAR simulations can be employed for designing of single RADAR components or develop complete systems including all RADAR installations and the vehicle. Complete RADAR simulation is a huge task. This task involves the RADAR to cover millions of electrical wavelengths. This is further increased by the number of times the RADAR updates central processing, number of antennas used, range and velocity of the RADAR system, and comparative velocity of environmental factors.

FIG. **1** illustrates a general block diagram of a negative feedback system **100**. The negative feedback system **100** has an input R and an output C, a summer/comparator **102**, a forward path function G **104** and a feedback path function H **106**. The summer/comparator **102** compares the input R with a sample B of the output C fed back through function H **106**, to produce an error signal E that is relative to the difference between the input R and the feedback sample B. This error signal E is fed to the main element G function **104** in the forward path. If the output signal C tends to drift upwards, the error signal E pushes it back downwards and vice versa. Thus, the negative feedback system **100** stabilizes the output signal C. The negative feedback system **100** finds applications in many systems for stabilizing frequency, output power, and many other functions.

FIG. **2** illustrates a general block diagram of a standard Phase Lock Loop (PLL) **200**. The PLL **200** is a frequency

feedback system comprising a reference clock **202**, a digital phase/frequency detector (PFD) **204**, a loop filter **206**, a Voltage Controlled Oscillator (VCO) **208**, and a frequency divider **210**.

The VCO **208** is the main output block in the forward path and is tuned to produce a frequency as set by a tuned circuit. The VCO **208** has a frequency output Fout that can be changed by a control voltage Vt over a pre-set range of frequencies.

The phase detector **204** is a comparator for both the clock input Fclock and the feedback sample from the output Fout divided by divider N **210**. The phase detector **204** compares the two input frequencies Fclock and Fout/N. When the two input frequencies are not equal, the device **204** acts as a frequency discriminator and produces either a negative or positive voltage, depending on the polarity of the frequency difference between the two inputs. When the two input frequencies are the device produces an error voltage Vt relative to the phase difference between the two equal frequencies.

The loop-filter **206**, filters and integrates the error signal produced by the phase detector **204** and feeds it to the VCO **208**. The loop filter **206** is usually based on passive components like resistors and capacitors, but also in some cases it is a combination of active devices like an operational amplifier and passive components.

The reference clock **202** is, in general, a low-frequency crystal oscillator signal source that feeds Fclock to the phase detector **204**, and to which the output signal Fout is "locked". The reference clock **202** is set at some frequency, for example, a standard frequency 10 MHz. The locking "mechanism" transfers some of the qualities of the reference clock **202** to the main output signal Fout. Its main features usually are: a) frequency stability over temperature—generally in the range of 0.1-5 ppm (parts per million), b) accuracy—Can be tuned to very high accuracy, c) very low phase-noise—Its phase-noise is transferred to the output signal multiplied by the ratio of 20*LOG(N) where N is the ratio between the output frequency and the clock frequency applied to the phase detector **204**.

The frequency divider **210** is based on digital devices like gates and flip-flops, through which the input frequency Fout is divided by a number N to produce Fout/N which is fed to the other input of the phase detector **204**. This number N is software controllable. The control signal comes usually from a microcontroller or from a PC or from anywhere that basically will send software control to the frequency divider **210** to change the division number N. The target of the division number N is to enable the output frequency of the frequency divider **210** to be equal to the clock frequency of the reference clock **202**.

The entire operational procedures of a standard Phase Lock Loop (PLL) 200 is as follows: If an input clock signal Fclock is applied, usually by a reference clock **202**, the phase detector **204** compares the phase and frequency of the input signal Fclock with that of the VCO **208** divided by N and generates an error voltage Vt that is related to the difference in the two signals. The error voltage Vt is then filtered and applied to the control of the VCO **208**, thereby varying the VCO **208** frequency in a direction that reduces the frequency difference between the two signals. When the frequencies of the two signals become sufficiently close, the feedback nature of the system causes the system to lock with the incoming signal. Once in lock, the VCO **208** frequency divided by N is identical with the input signal Fclock, except for a finite phase difference which is necessary to generate the corrective error voltage Vt to shift the VCO **208** frequency to the input signal frequency Fclock, thus keeping the system in the lock.

When the division number N is changed, say for example by 1, the output frequency Fout jumps exactly by a step. In an example, if the reference clock **202** generates a frequency 1 MHz, then every time the division number N changes by steps of 1, the output frequency Fout changes by equal steps of 1 MHz.

Like all negative feedback systems, the PLL **200** has a loop bandwidth set by the component parameters and the loop filter **206**. In other words, the PLL **200** is a sophisticated frequency multiplier with a built-in narrowband, automatically tuned band-pass filter as the output frequency Fout is basically Fclock multiplied by the number N. The loop bandwidth is also responsible directly for how fast the output frequency of PLL **200** may change between different frequencies. The PLL **200** is a device where the VCO **208** is locked to a single clock reference signal which is very low but also very clean and very stable and the output frequency can be changed by equivalent steps by controlling the frequency divider **210** in the feedback loop.

FIG. **3** illustrates a simplified drawing of a digital phase/frequency detector **204**. A phase detector or phase comparator is a frequency mixer, analog multiplier or logic circuit that generates a voltage signal which represents the difference in phase between two signal inputs. It is an essential element of the phase-locked loop (PLL). A specialized variant that additionally detects frequency is referred to as Phase Frequency Detector (PFD). A phase-frequency detector is an asynchronous sequential logic circuit which determines which of the two signals has a zero-crossing earlier or more often. When used in a PLL application, the lock can be achieved even when it is off frequency. Such a detector has the advantage of producing an output even when the two signals being compared differ not only in phase but in frequency.

The phase/frequency detector **204** compares two input frequencies Fclock and Fout/N. When the two input frequencies are not equal, it acts as a frequency detector and produces one or zeros to produce a voltage control Vt that pushes corresponding VCO **208** in the direction of the reference. In other words, if the VCO **208** is above the reference then the voltage control Vt is high to push the VCO **208** down and vice versa. When the two input frequencies are the same and a frequency lock is achieved, the phase detector **204** acts as a phase detector and compares the two phases and continues to produce an error voltage to control the frequency and phase of the output device.

FIG. **4** illustrates an example of an active filter as applied to a general PLL **400**. The kind of loop filter i.e. passive filter or active filter can be chosen on the basis of specific requirement. A passive loop filter is based on resistors and capacitors only, while an active loop filter is based on an amplifier and a capacitor-resistor network in the feedback system. A passive filter is preferred in cases where, a reference PLL is of a single frequency and will need only a single voltage in order to stay in that single frequency. The other reasons being simplicity, cost and most advantageously no addition of noise, as active devices tend to add additional noise to the system. However, active filters find more acceptance because of the possibility of amplification of the input signal. Amplification is made possible by an operational amplifier employed in the active filter.

The loop filter **206**, of FIG. **2**, is an active filter that includes an operational amplifier **402** and a capacitor-resistor network **404** in the feedback loop. In some instances, the

phase detector **204** of the PLL **200** may produce voltage up to 5 volts but the corresponding VCO **208** may need a voltage of above 5 volts, say, for example, up to 18 volts in order to reach its complete range, so the active filter **206** facilitates not only filtering but also provides the capability to go to higher voltages.

FIG. **5** illustrates the principle of sample-and-hold mechanism **500**. The first sample and hold circuit **502** includes a switch S and a hold capacitor CH. The operation of the switch S is controlled by the sample control. When the switch S is closed, a voltage sample of the input frequency is sampled and when the switch is opened, the voltage sample is held on the hold capacitor CH.

The second sample and hold circuit **504** includes two buffers A**1** and A**2** with unity gain for isolation purposes, in addition to the switch S and the hold capacitor CH. The buffer A**2** is preferably an electronic buffer, so that the hold capacitor CH does not discharge parasitically between consecutive samples. In other words, the hold capacitor CH holds the voltage between samples.

FIG. **6** illustrates an example of practical implementation of a comb generator and sampling phase detector. The schematic shows a Step Recovery Diode (SRD) as comb generator feeding the dual Schottky diode that acts as a phase detector. The implementation of circuit **600** including a Step Recovery Diode (SRD) **602** as a comb generator and the dual Schottky diodes **604** and **606** as a phase detector.

The input to the circuit **600** in this example is a clock input of 100 MHz sine wave. The SRD **602** is a special device that turns the 100 MHz sine wave input into a very narrow pulse train of the same frequency, so it acts as a comb generator. The two Schottky diodes **604**, **606** acts as switches and act as sampling switches. The RF voltage (output from the corresponding VCO) to be sampled is connected to a point between the two diodes **604** and **606**. The SRD **602** creates an output of positive and negative pulses. The positive and negative pulses act as control signals to the diodes **604** and **606** that act like switches. The sampled voltage output is an error DC voltage which is created by sampling the RF input through the dual Schottky diodes **604** and **606**. The output of the RF signal is sampled whenever the diodes **604** and **606** are opened by the narrow pulses coming from the SRD **602**. The voltage sample is held on the capacitors C following the diodes **604** and **606**.

FIG. **7** illustrates a schematic of the comb generator and sampling phase detector with a clock pre-amplifier and two DC buffers following the phase detector. The voltage samples are held on two very small capacitors (which are basically the input capacitance of the voltage buffers, no need for external capacitors) on both sides of the dual diode pair, so as not to enable the whole capacitor to discharge parasitically between the samples. These capacitors are buffered by a couple of ultra-low input bias current buffers to prevent discharge between samples. The two voltages are summed, fed to a loop filter, whereby the clean Vt is fed to the VCO to control the frequency.

This implementation of sampling phase detector creates an analog phase detector, very similar to a mixer. The analog sampling phase detector has a certain defined locking space or locking distance, and it does not lock from a frequency difference like the phase/frequency digital detector. It has some locking range and only within that locking range, the VCO locks by itself on the reference. In a sampling PLL, the VCO does not lock on the reference, but on the Nth harmonic of the reference. In other words, one can lock a 9 GHz on the 90th harmonic of the 100 Megahertz clock. This is done as the input frequency is sampled every 100 cycles, not every cycle.

This type of product may contain some "search mechanism" to help lock the PLL. The most common one involves a positive feedback on the loop filter itself. While the loop is not locked, the loop filter acts as a very low-frequency oscillator that drives the VCO back and forth across the frequency range. When it passes close enough to the harmonic of the clock, it will lock and stay locked. A nice feature of this mechanism is that it turns off automatically when the loop locks. This happens because of the nature of the loop as a negative feedback system.

However, this type of search mechanism suffers from many problems, its operation is subject to temperature changes and it makes this product difficult to produce, tune and sell successfully.

FIG. **8** illustrates a phase-noise plot **800** of an example free running Voltage Control Oscillator (VCO) in the frequency domain (spectrum analyzer), without being locked in a PLL. As said before, Phase-noise is a key element in many RF and radio communications systems as it can significantly affect the performance of systems. Phase-noise is the frequency domain representation of rapid, short-term, random fluctuations in the phase of a waveform, caused by time domain instabilities also referred to as "jitter".

For example, in the frequency domain, where the scales are amplitude vs. frequency, ideally, a frequency of 100 MHz may look like a single line staying at exactly 100 MHz However, practically with modern equipment in the laboratory, amplitude vs frequency may not look like a single line but it will look like a single line with a "skirt" **802** which goes wider and wider as we go down. The phase-noise plot **800** looks like the skirt **802** on the left and the right of the exactly desired frequency f_o. The quality, height, width of the skirt **802** determines how the phase-noise may affect the system or the performance of the system. So, it is desirable to minimize phase-noise as much as possible is to improve the system performance.

Phase-noise is another term to describe short-term frequency instability. The signal generated by a frequency source is never practically "clean". Its frequency is never absolutely stable at the desired value. It has "Phase-noise" which is frequency shifting, i.e. small frequency shifts at different rates and different amplitudes of the main frequency. It changes around the center set frequency f_o at different rates and amplitudes. In the time domain, the phase-noise may be referred to as jitter. Long-term frequency stability is the drift of the center frequency over time or over temperature.

FIG. **9** illustrates a phase-noise plot **900** of an example Voltage Control Oscillator (VCO) in the frequency domain (spectrum analyzer), compensated by being locked in a PLL.

The upper line **904** is the free running VCO phase-noise, before it is locked in a PLL, and the lower line **902** is the shaped VCO phase-noise. In the PLL, the principle of locking the VCO to a reference frequency attenuates the phase-noise of the VCO, in an amount related to the loop bandwidth. Outside the loop bandwidth, the VCO noise remains almost same as the phase-noise without the PLL, while inside loop bandwidth it is attenuated more and more as offset frequency from the main carrier is reduced. At very high frequency, i.e. above the loop bandwidth, the locking almost has no effect, as the phase detector correction signal is not fast enough to reach the VCO for very fast changes or very fast disturbances. However, inside the loop bandwidth or at low frequencies, the compensated phase-noise of the

VCO is much lower than that of the free running VCO. All the frequencies that are close to the center of the frequency fo are easy to detect and compensate.

FIG. **10** illustrates two plots **1000**: (a) a simulation of phase-noise of an example PLL, and (b) an actual measurement. FIG. **10** (*a*) illustrates a simulation graph of phase-noise of an example PLL. The simulation graph shows the overall phase-noise of the example PLL and includes the contribution of all the components that contribute to the phase-noise. The simulation graph illustrates first, second and third regions **1002**, **1004** and **1006** of the phase-noise. The first region **1002** which is very close to the carrier depicts a steep line which basically comes from the reference clock such as the Temperature Controlled Crystal Oscillator (TCXO, or other reference clock device). The first region depicts the noise of the TCXO, multiplied by 20 log N, where N is the ratio of output frequency to the clock frequency. The second region **1004** depicts a flat phase-noise which is basically the noise floor of the digital phase detector multiplied by the same ratio of 20 log N. The third region **1006** depicts a steep line which is the inherent VCO phase-noise not affected by the loop bandwidth and locking phenomenon. The dashed line **1008** depicts the VCO "corrected" phase-noise inside loop bandwidth. Below the flat area, the compensated VCO phase-noise does not affect the overall result because it is way below the noise floor of the phase detector multiplied by that ratio. The actual measurement of phase-noise of an example PLL is illustrated in FIG. **10** (*b*). One can see clearly the similarity between the two curves.

FIG. **10** illustrates a phase-noise plot **1100** of a closed loop PLL, showing clearly the effect of the phase detector multiplication number 20*LOG(N) within loop bandwidth. The phase-noise plot **800** illustrates phase-noises on both sides of the carrier frequency fo, where the left side is a mirrored image of the right side. The phase-noises on both sides of the carrier folook like it is passing through a band-pass filter.

As illustrated, on both sides, the in-band phase-noise inside the loop bandwidth is flat in shape and is equal to the phase detector and/or the reference clock noise multiplied by 20 log N. At the point of the loop bandwidth, the phase-noise goes up before going down again. This is due to the addition of 3 dB due to a combination of phase-noise of the free running VCO and the phase detector. The upper straight line **1102** depicts a phase-noise contributed by the phase detector at N**1** and the lower straight line **1104** depicts a phase-noise contributed by the phase detector at N**2**. It can be seen that there is the difference in phase-noise in the flat area, due to two different "N" numbers. The phase detector contributes a higher in-band phase-noise at a higher value of N.

Thus, in order to achieve low phase-noise, it is essential to: a) choose components such as phase detector and reference clock with the lowest inherent phase-noise possible, and b) lower the ratio number N as much as possible.

FIG. **11** illustrates plot **12902200** of measurement in terms of phase-noise in 1 Hz bandwidth at a Δf offset frequency from the carrier. The phase-noise expression is usually in dBc, i.e. dB relative to the carrier c power level Ps, in other words how low it is compared to the carrier per Hz, in a bandwidth of 1 Hz. That is basically the term that is used for phase-noise, dBc per Hertz (dBc/Hz) at a certain Δf from the carrier.

As an example for the measurement method, suppose ΔF is 10 KHz, the phase-noise power level Pss is measured at the level of −70 dBm on the spectrum analyzer, and the carrier power level Ps is measured at the level of 10 dBm, the ratio between the Ps 10 dBm and the PssB −70 dBm at 10 KHz from the carrier is therefore 80 dB, so the phase-noise at 10 KHz offset from carrier and is −80 dBc/Hz.

For many systems, the important parameter to evaluate performance is not the phase-noise measured at a single frequency offset from the carrier, but the integrated phase-noise from one offset frequency to another one. Following are four different equations and terms to define integrated phase-noise:

$$\int L(f)df$$

$$S_{phi}(f) = \left(\frac{180}{\pi}\right) \cdot \sqrt{2 \cdot \int L(f)df}$$

$$S_{nu}(f) = \sqrt{2 \cdot \int L(f) \cdot f^2 df}$$

$$S_y(f) = \left(\frac{s_{nu}(f)}{f_{osc}}\right)$$

Where the first equation describes single sideband phase-noise [dBc]

The 2nd equation describes the spectral density of phase modulation, also known as RMS phase error (degrees)

The 3rd equation describes the spectral density of frequency fluctuations, also known as RMS frequency error or residual FM (Hz)

The 4th equation describes the spectral density of fractional frequency fluctuations

For example, the first equation defines the Phase-noise in dBc. It can be translated by the 2nd equation to degrees (relevant in respect of learning modulation schemes). As per further equations, the phase-noise can also be translated in terms of Hz and time domain phase jitter seconds.

FIG. **13** illustrates a general block diagram **1300** of an example dual loop PLL. The main target of the dual loop design is to reduce the multiplication number N in the main PLL.

The dual loop PLL **1300** includes an upper PLL **1302**, referred to as a main PLL **1302**, and a lower PLL **1304**, referred to as a reference PLL **1304**, a TCXO **1306** operating as a master clock, feeding a clock signal Fc to both the primary PLL **1302** and the reference PLL **1304**.

The reference PLL **1304** includes a first phase detector **1314**, and a single frequency first VCO **1316** that operates at a reference frequency Fr. The reference frequency Fr is fed to the first input of a down convert mixer **1312**.

The main PLL **1302** includes a second phase detector **1308** and a second VCO **1310** that generates an output frequency range from F**1** to F**2**. A sample of the output frequency range F**1** to F**2** is fed to the second input of the down-convert mixer **1312** and mixed with a single reference frequency Fr. The output from the down-convert mixer **1312** is at a much lower frequency (F**1** to F**2**)−Fr. This lowered frequency is fed back to the second phase detector **1308** through a frequency divider **1318** of value N**1**.

Therefore: a) Without the down-convert mixer **1412**: F**1** to F**2**=NxFc, b) With the down-convert mixer **1312**: (F**1** to F**2**)−Fr=N**1**×Fc. As a result, there is a reduction in the number N: N**1**/N=((F**1** to F**2**)−Fr)/(F**1** to F**2**).

The N**1** number is basically the division number that the frequency divider **1318** will use to divide the output of the mixer **1312** and feed to the second phase detector **1308**. The value of N**1** is set as minimal, as the output from the mixer **1312** is at a much lower frequency than original frequency range F**1** to F**2**.

To give an example: a) Suppose Fc=1 MHz, b) Suppose F1 to F2=10,000 to 11,000 MHz Then N=10,000 to 11,000. Now If Fr=9000 MHz, then ((F1-F2)−Fr)=1000 to 1900 MHz Then N1=1000 to 1900. Thus, the value of N is reduced from 11,000 to 1900. In dB, it is a ratio of 15 dB. This means, that the phase-noise is reduced by a factor of 15 dB.

The disadvantage of the example dual loop design is that while nicely reducing the number N in the main PLL, the reference PLL, containing a digital phase/frequency detector becomes the main factor contributing to the overall output phase-noise.

FIG. **14** illustrates a general block diagram **1400** of an example sampling PLL. The sampling PLL **1400** includes a TCXO **1402**, a comb generator **1404**, a sampling phase detector **1406**, a loop filter **1408**, and a VCO **1410**. The sampling PLL **1400** does not include digital phase/frequency detector and a frequency divider. Thus, no digital noise floor is generated that can be multiplied and affect the performance of the system.

The TCXO **1402** feeds the clock signal Fclock to the comb generator **1404**. The comb generator **1404** is a device that changes the input sine wave signal at frequency Fclock to an output signal of very narrow pulses at the same frequency as the input sine wave signal.

The pulse output from the comb generator **1404** is used as a control signal to the sampling phase detector **1406**. The sampling phase detector **1406** receives an RF signal of frequency Fout from the VCO **1410** and includes two diodes acting as switches to sample the RF signal by opening and closing the diodes based on the narrow pulses from the comb generator **1404**. The sampled voltage Vt produced is "held" on capacitors and buffered until the next sample period. The voltage samples are always at the same level; thus, a DC voltage Vt is generated by the sampling phase detector **1406**. The loop filter **1408** cleans and filters the DC voltage Vt and provides it to the VCO **1410** to control the VCO frequency Fout. Fout=Fclock*N, where N is the Nth spectral harmonic line in the "comb" spectrum.

FIG. **15** illustrates block diagram **1500** depicts how the impulse or "comb" generator **1404** changes a wave shape of a signal from sine wave **1502** to narrow pulses in **1504**. A frequency source **1506** generates the input sine wave **1502** of frequency F1 and time period T1.

The comb generator **1404** turns the input sine wave **1502** to a series of very narrow pulses **1504** with same time period T1, and a pulse bandwidth as tp in the time domain. For example, if the frequency of input sine wave **1502** is 100 MHz, then the impulse train generator **1508** generates a series of very sharp narrow pulses **1504** of the same frequency.

FIG. **16** illustrates an example output **1600** of a comb generator **1404** in the frequency domain. In the frequency domain (spectrum analyzer screen), the output **1600** of the comb generator **1404** looks like a "comb", i.e. a row of lines extending up to very high frequency. In theory, if the bandwidth of the clock pulse is infinitesimal, the row of lines appears with equal amplitude to infinity. The output **1600** looks like a series of lines, with the spacing between the lines same as the initial frequency. In an example, if the initial frequency is 1 GHz, the spectrum of lines is 1 GHz apart.

FIG. **17** illustrates a block diagram **1700** of an ultra-low phase-noise frequency synthesizer as suggested in a first embodiment. The ultra-low phase-noise frequency synthesizer **1700** includes two Phase Lock Loops (PLLs). One is a main PLL **1710** and the other one is a reference PLL **1718**.

The main PLL **1710** comprises a high-frequency low noise Direct Digital Synthesizer (DDS) **1702** to generate at least one clock signal Fc2 of the variable frequency range. The high-high-high-frequency low noise DDS **1702** generates the at least one clock signal Fc2 of variable frequency range by taking input from at least one software controllable instructions and at least one DDS clock signal. The frequency of the at least one clock signal Fc2 is always lower than the frequency of the at least one DDS clock signal. The at least one DDS clock signal is generated by a first fixed frequency divider **1714**. The high-frequency low noise DDS **1702** forwards the generated at least one clock signal Fc2 of variable frequency range towards a Digital Phase Frequency Detector **1704**.

The Digital Phase Frequency Detector **1704** compares two signals coming from two directions and generates at least one signal. One signal is the at least one clock signal Fc2 of variable frequency range generated by the high-high-high-frequency low noise DDS **1702**. The second signal is at least one signal of frequency Fif/N1 generated by a second fixed frequency divider **1712**. The Digital Phase Frequency Detector **1704** compares these two signals and generates at least one first control voltage Vt1 and forwards it towards a primary Voltage Control Oscillator (VCO) **1706**. The primary Voltage Control Oscillator (VCO) **1706** generates at least one output signal of frequency Fout from the received at least one first control voltage Vt1. The main PLL **1710** further comprises a down convert mixer **1716**.

The primary role of the reference PLL **1718** is to help the main PLL **1710** in reducing the phase-noise present in the at least one output signal Fout. The reference PLL **1718** comprises a reference clock (for example a Temperature Compensated Crystal Oscillator (TCXO)) **1724** to generate at least one first clock signal of a fixed single frequency Fc1. Further, the reference PPL comprises a sampling phase detector **1722** (that includes the comb generator and the sampling phase detector) to generate at least one-second control voltage Vt2 and a reference Voltage Control Oscillator (VCO) **1720**.

One important thing to notice here is that unlike other dual loop designs, the reference PLL **1718** uses the sampling phase detector **1722**. The reference PLL **1718** does not use kind digital devices like the Digital Phase Frequency Detector **1704**, or the first fixed frequency divider N1 **1714**. Simultaneously the reference clock **1724** present in the sampling PLL **1718** is also a very low noise generating device. Due to these reasons, the contribution of phase-noise from the reference PLL **1718** to the main PLL **1710** becomes close to negligible. The reference Voltage Control Oscillator (VCO) **1720** generates at least one reference signal Fr and forwards it towards the down-convert mixer **1716**. The reference PLL **1718** plays a major part in all relevant communications and similar systems by being part of various frequency synthesizers, and also as a standalone frequency source for all the systems of up and down conversion processes in the same equipment.

The down-convert mixer **1716** receives at least one reference signal of frequencies Fr and at least one output signal of frequency Fout and generates at least one intermediate signal of frequency Fif and forwards it towards a second fixed frequency divider **1712**. The second fixed frequency divider **1712** generates at least one signal of frequencies Fif/N1 by dividing the incoming at least one signal of frequency Fif by a predefined factor. The second fixed frequency divider **1712** forwards the generated at least one signal of frequencies Fif/N1 towards the Digital Phase Frequency Detector **1704**. The primary VCO **1706** forwards

the at least one output signal Fout towards a fixed frequency multiplier **1708** to generate at least one final output signal Fout final.

It is important to notice that frequency divider **1712** is optional and the main PLL can operate without division of Fif.

To explain the above-disclosed disclosures with an example let's say the reference clock **1724** generates the at least one first clock signal of a fixed single frequency Fc**1** 100 MHz. The sampling phase detector **1722** generates the second control voltage Vt**2** by sampling the at least one first clock signal of a fixed single frequency Fc**1** 100 MHz and forwards the sampled values of the at least one first clock signal of a fixed single frequency Fc**1** 100 MHz towards the reference Voltage Control Oscillator (VCO) **1720**. The reference Voltage Control Oscillator (VCO) **1720** generates the at least one reference signal Fr and forwards it towards the down-convert mixer **1716**. In an example, the reference VCO **1720** generates a frequency of 9.4 GHz.

In the example, the first frequency divider **1714** divides the generated reference signal of frequency 9.4 GHz by a predefined factor of 3 to generate the at least one DDS clock signal. The high-high-frequency low noise DDS **1702** receives the at least one DDS clock signal, and based on the at least one software controllable instructions, generates the at least one clock signal Fc**2** of the variable frequency range from 0.1 GHz to 0.225 GHz.

In the example, the primary VCO **1706** generates the at least one output signal of frequency Fout ranging from 9.5 GHz to 9.625 GHz. The down-convert mixer **1716** mixes the at least one output signal of frequency Fout ranging from 9.5 to 9.625 GHz with the reference signal Fr at frequency 9.4 GHz to generate the at least one intermediate signal Fif having frequency ranges from 0.1 GHz to 0.225 GHz. Since the at least one clock signal Fc**2** ranges from 0.0.1 GHz to 0.225 GHz, the second fixed frequency divider **1712** is set to divide the at least one intermediate signal Fif by a predefined factor of 1, (which means practically no divider needed in this case) to generate the at least one signal of frequencies Fif/2 ranging from 0.1 GHz to 0.225 GHz.

The fixed frequency multiplier **1708** multiplies the at least one output signal Fout ranging from 9.4 GHz to 9.625 GHz by a predefined factor of 8 to generate the at least one final output signal Foutfinal ranging from 76 GHz to 77 GHz. It is easier and relatively inexpensive to implement the chip design of the frequency synthesizer **1700** for output frequencies 9.4 GHz to 9.625 GHz, and then multiply the at least one output signal Fout by 8 to generate the at least one final output signal Foutfinal in the range of 76 GHz-77 GHz.

The down-convert mixer **1716** lowers the frequency of the at least one output signal Fout, to reduce the ratio of the frequencies of the second clock signal and the feedback signal. Instead of feeding the at least one output signal Fout directly to the Digital Phase Frequency Detector **1704**, it is mixed down to create at least one signal with a much lower frequency and obtain a much lower value of the second fixed frequency divider **1712** or it is not needed as in this example.

As the primary phase-noise present in the ultra-low phase-noise frequency synthesizer **1700** is due to the product of the noise present in the high-frequency DDS **1702** and the second fixed frequency divider **1712**, the less the value of the second fixed frequency divider **1712** will be, the less will be the generated phase-noise in the ultra-low phase-noise frequency synthesizer **1700**. Therefore, when the second fixed frequency divider **1712** is equal to 1, the DDS signal noise is multiplied by the number 1 which means it is transferred as is to the output and this achieves a very ultra-low noise.

The reduction in the ratio of the frequencies leads to a reduction in a phase-noise of the final output signal Foutfinal. The comparison frequency is much lower, so that the number N by which the noise is multiplied inside the main PLL **1710** is much lower. In an example, the even if the ratio of second fixed frequency divider=2 reduces the phase-noise of the final output signal Foutfinal by a factor of 20-40 dB compared to a single PLL design. For example, phase-noise at 100 KHz Δf from the carrier with standard PLL synthesizers is approximately −106 dBc/Hz. With the proposed frequency synthesizer **1700**, the phase-noise at 100 KHz Δf from the carrier could be in the range of −130-135 dBc/Hz, causing a significant improvement of 24-29 dBs

To summarize, the drastic improvements achieved in reducing phase-noise in the ultra-low phase-noise frequency synthesizer **1700** is based on the following: a) use of Dual PLL approach to reduce the multiplication number N**2**, b) use of sampling PLL **1718** as the reference PLL, to make its noise contribution and reference PLL phase-noise negligible, c) use of DDS **1702** to provide low noise, high frequency input to the main PLL **1710**, and d) use of high-frequency Digital Phase Frequency Detector **1704** in the main PLL **1710**.

In this embodiment, the ultra-low phase-noise frequency synthesizer **1700** is implemented in form of a module. In another form of this embodiment, this design of the ultra-low phase-noise frequency synthesizer **1700** can be implemented not only as a part of the big module, but also as an independent, separate chip, which can become a part of the front-end module of a RADAR transceiver. The synthesizer can be implemented in an advanced technology for example but not limited to, like SiGe or GaAs.

FIG. **18** illustrates a block diagram **1800** of an ultra-low phase-noise frequency synthesizer as suggested in a second embodiment. The low phase-noise frequency synthesizer **1800** includes two Phase Lock Loops (PLLs). One is a main PLL **1812** and the other one is a reference PLL **1818**. In this embodiment, the ultra-lowphase-noise frequency synthesizer **1800** comprises one single reference clock (for example a Temperature Compensated Crystal Oscillator) **1802** which provides input clock signals to both the main PLL **1812** and the reference PLL **1818**.

The main PLL **1812** comprises of a Fractional-N synthesizer chip **1804**, a primary Voltage Controlled Oscillator (VCO) **1810** and a down convert mixer **1816**. The Fractional-N synthesizer chip **1804** includes a high-frequency Digital Phase Detector **1806** and a software controllable variable frequency divider N**1** **1808**.

The reference clock **1802** forwards the generated at least one clock signal of fixed frequency Fc towards the high-frequency Digital Phase Detector **1806** which is located inside the Fractional-N synthesizer chip **1804**. On one hand, the high-frequency Digital Phase Detector **1806** receives the at least one clock signal of fixed frequency Fc. On the other hand, the high-frequency Digital Phase Detector **1806** receives at least one signal of frequency Fif/N**1** generated by the software controllable variable frequency divider N**1** **1808**. The high-frequency Digital Phase Detector **1806** compares these two signals, generates at least one first control voltage Vt**1** and then forwards the generated at least one first control voltage Vt**1** towards the primary VCO **1810**. The primary VCO **1810** generates at least one output signal of frequency Fout from the received at least one first control voltage Vt**1**.

The primary role of the reference PLL **1818** is to help the main PLL **1812** to reduce the phase-noise present in the at least one output signal Fout. The reference PLL **1818** comprises a sampling phase detector **1822** and a reference Voltage Control Oscillator (VCO) **191820**.

One important thing to notice here is the application of the sampling phase detector **1822**. The sampling PLL **1818** does not use kind digital devices like the Digital Phase Detector **1806**, or the software controllable variable frequency divider N **1808**. Due to these reasons, the contribution of phase-noise from the sampling PLL **1818** to the main PLL **1812** becomes close to negligible.

The sampling phase detector **1822** receives the same at least one clock signal of fixed frequency Fc generated by the reference clock **1802**, generates at least one-second control voltage Vt**2** and forwards it towards the reference VCO **191820**. The reference VCO **191820** generates at least one reference signal Fr and forwards it towards the down-convert mixer **1816**.

The down-convert mixer **1816** based on the received at least one reference signal of frequency Fr and the at least one output signal of frequency Fout generates at least one intermediate signal of frequency Fif and forwards it towards the software controllable variable frequency divider N**1** **1808** located inside the Fractional-N synthesizer chip **1804**. The software controllable variable frequency divider N**1** **1808** generates at least one signal of frequencies Fif/N**1** by dividing the incoming at least one intermediate signal of frequency Fif by at least one variable value of N**1**. The Fractional-N synthesizer chip **1804** varies the value of N**1** by executing appropriate software instructions. The software controllable variable frequency divider N**1** **1808** then forwards the generated at least one signal of frequency Fif/N**1** towards the Digital Phase Detector **1806**.

The primary VCO **1810** forwards the at least one output signal Fout towards a first fixed frequency multiplier **1814** and generate at least one final output signal Foutfinal by multiplying the at least one output signal Fout by a predefined factor.

To explain the second embodiment with an example let's say the reference **1802** generates the at least one clock signal of fixed frequency Fc 100 MHz to Both the main PLL **1812** and the reference PLL **1818**. The phase-noise of the reference PLL **1818** is generally very low due to the principle of sampling and also to the presence of the input reference clock **1802** which is itself a very low noise generating device.

The sampling phase detector **1822** generates the second control voltage Vt**2** based on the at least one clock signal of fixed frequency Fc 100 MHz and forwards the second control voltage Vt**2** towards the reference VCO **191820**. The reference VCO **191820** generates at least one reference signal Fr and forwards it towards the down-convert mixer **1816**. In an example, the reference VCO **191820** generates reference signals of frequency 9.4 GHz.

In the example, the primary VCO **1810** generates the at least one output signal of a frequency Fout ranging from 9.5 GHz to 9.6257 GHz. The down-convert mixer **1816** mixes the at least one output signal of frequency Fout ranging from 9.5 GHz to 9.625 GHz with the reference signal of frequency 9.4 GHz to generate the at least at least one intermediate signal of frequency Fif ranging from 0.1 GHz to 0.225 GHz.

Based on the at least one clock signal of fixed frequency Fc, the Fractional-N synthesizer chip **1704** determines the value of the software controllable variable frequency divider N**1708**, so as to generate at least one feedback signal of frequency Ff=Fif/N**1**.

The frequency range 9.5 GHz to 9.625 GHz easier and relatively inexpensive to implement the chip design of the low phase-noise frequency synthesizer **1800**, and then multiply the output frequencies by 8 in frequency multiplier **1814** to obtain the final output frequencies in the range of 76 GHz-77 GHz.

The down-convert mixer **1816** lowers the frequency of the output signal Fout, to reduce a ratio of frequencies of the second clock signal and the feedback signal. Instead of feeding the output frequency Fout directly to the Digital Phase Detector **1806**, it is mixed down to create a much lower frequency, and thus a much lower value of N**1**. A reduction in the ratio of the at least one clock signal of frequency Fc and the at least one feedback signal of frequency Ff leads to a reduction in a phase-noise of the final output signal Foutfinal. The feedback frequency is lowered down, so that the number N**1** by which the noise is multiplied inside the main PLL **1812** is also lowered down. If the output frequency Fout is in the range of 9.5 GHz, and it has to be compared with a clock of 100 MHz, the ratio N of 9.5 GHz and 100 MHz is around 95, but if the output frequency Fout is mixed down to about 0.2 GHz by the down-convert mixer **1816**, then the ratio N**1'** of 0.2 GHz and 100 MHz maybe only 2 instead of 95 thereby significantly reducing the phase-noise of the low phase-noise frequency synthesizer **1800**.

The improvement in the phase-noise of the low phase-noise frequency synthesizer **1800** is based on following: a) use of dual PLL to reduce the multiplication number N, b) use of sampling PLL **1818** as the reference PLL to make its noise contribution negligible, c) use of high frequency low noise reference clock **1802** to provide high frequency input to the main PLL **1812**, d) use of high frequency Fractional-N synthesizer **1814** in the primary PLL **1806**.

In this second embodiment, the ultra-low phase-noise frequency synthesizer **1800** is implemented in form of a module. In another form of this embodiment, this design of the ultra-low phase-noise frequency synthesizer **1800** can be implemented not only as a part of the big module, but also as an independent, separate chip, which can become a part of the front-end module of a transceiver. The ultra-low phase-noise frequency synthesizer **1800** can also be implemented in advanced technology for example like SiGe or GaAs.

FIG. **19** illustrates a block diagram **1900** of the sampling Phase Lock Loop (PLL) system as suggested in a third embodiment. The sampling PLL system **1900** includes a Temperature Compensated Crystal Oscillator (TCXO) **1902** as an example of the reference clock, a comb generator **1904**, a sampling phase detector **1906**, a two-way DC switch **1908**, a loop filter **1910**, a Voltage Controlled Oscillator (VCO) **1912**, and a Digital Phase Frequency Detector **1914**. The TCXO **1902** is configured to generate at least one clock signal of frequency Fc z, which is applied to both of the comb generator **1904** and the Digital Phase Frequency Detector **1914**. The sampling PLL system **1900** contains two PLL loops. One is a Sampling PLL loop **1916** and the other is a Digital PLL loop **1918**.

The principle of operation in this embodiment is this: Initially, the two-way DC switch **1908** remaining closed with the Digital Phase Frequency Detector **1914**. Due to this only the Digital PLL loop **1918** is remains operational and the VCO **1912** gets locked to the at least one clock signal of frequency Fc generated by the reference clock TCXO **1902**. The Digital Phase Frequency Detector **1914** also generates at least one lock detect signal Vld.

Once VCO **1912** gets locked to the at least one clock signal of frequency Fc generated by the reference clock TCXO **1902**, the at least one lock detect signal Vid generated by the Digital Phase Frequency Detector **1914** changes the two-way DC switch **1908** to the Sampling PLL loop **1916**. Due to this the Sampling PLL loop **1916** gets closed and the Digital PLL loop **1918** gets opened. Since the VCO **1912** is already locked at the correct frequency, the Sampling PLL loop **1916** will remain closed. One important thing to notice here is that the loop filter **1910** is common to both the Sampling PLL loop **1916** and the Digital PLL loop **1918**. As the loop filter, **1910** is made up of a plurality of resistors and capacitors which are charged to the right tuning voltage Vt which is applied to the VCO **1912**. When the Sampling PLL loop **1916** gets closed and the Digital PLL loop **1918** gets opened, the plurality of resistors and capacitors present in the loop filter **1910** do not change their tuning voltages in that step. In other words, the Digital PLL loop **1918** is used to lock the VCO **1912** with the exact right frequency generated by the TCXO **1902** and the Sampling PLL loop **1916** is used to achieve low phase-noise.

The two-way DC switch **1908** is configured to be switched between the sampling phase detector **1906** and the Digital Phase Frequency Detector **1914** based on a status of the lock detect signal Vld generated by the Digital Phase Frequency Detector **1914**. For example, the two-way DC switch **1908** is configured to be connected to the Digital Phase Frequency Detector **1914** when the lock detect signal Vld islow and configured to be connected to the sampling phase detector **1906** when the lock detect signal Vld is high.

In the third embodiment, when the lock detect signal Vld is low, the two-way DC switch **1908**, the loop filter **1910**, the VCO **1912** and the Digital Phase Frequency Detector **1914**, form a Digital PLL loop **1918**. Whereas, when the lock detect signal Vld is high, the comb generator **1904**, the sampling phase detector **1906**, the two-way DC switch **1908**, the loop filter **1910**, and the VCO **1912** forms a sampling PLL loop **1916**.

As said, initially, the two-way DC switch **1908** is connected to the Digital Phase Frequency Detector **1914**, as the lock detect signal Vld is low due unlock state. In the Digital PLL loop **1918**, the Digital Phase Frequency Detector **1914** generates a first DC output signal Vtd based on a comparison of the at least one clock signal of frequency Fc, and at least one output signal of frequency Fr, the loop filter **1910** filters the first DC output signal Vtd and generates the control voltage Vt, and the VCO **1912** generates the output signal frequency based on the control voltage Vt. In an example, the VCO **1912** is configured to generate either an output signal of frequency Fr of 11.75 GHz or 12.75 GHz chosen by software control to the Digital PLL loop **1918**.

As soon as the Digital PLL loop **1918** is locked at the output frequency Fr, the lock detects signal Vld turns high, the two-way DC switch **1908** disconnects from the Digital Phase Frequency Detector **1914** and connects to the sampling phase detector **1906**, forming the sampling PLL loop **1916**.

So once locked, the lock detector signal Vld from the Digital Phase Frequency Detector **1914** controls the two-way DC switch **1908** to switch to the sampling PLL **1916**. The loop filter **1910** contains plurality of capacitors and resistors that are already charged to the correct tuning voltage Vt of the VCO **1912**, and since voltage on the plurality of capacitors and resistors cannot change in a "jump", there would not be a transient, and the VCO **1912** may continue receiving the same control voltage Vtd. The sampling PLL system **1900** remains locked at the same frequency but now through the sampling phase mechanism.

In the Sampling PLL loop **1916**, the comb generator **1904** receives the at least one clock signal of frequency Fc and generates at least one comb signal Fcomb. The at least one comb signal Fcomb is basically a plurality of narrow pulses, which are repeating at the same frequency Fc which is the frequency of the at least one clock signal generated by the TCXO **1902**. The sampling phase detector **1906** after receiving the at least one comb signal Fcomb generates a second DC output signal Vts based on the at least one comb signal Fcomb. The loop filter **1910** generates the control voltage Vt based on the second DC output signal Vts and the VCO **1912** remains locked at the output frequency Fr based on the control voltage Vt.

At the execution of lock by the Digital Phase Frequency Detector **1914**, the first DC output signal Vtd becomes equal to the second DC output signal Vts. Further, the loop filter **1910** is common to the sampling PLL loop **1916** and the Digital PLL loop **1918** so as to maintain a similar control voltage Vts while switching from the Digital PLL loop **1918** to the sampling PLL loop **1916** and vice versa.

Another feature is that if by a chance, the sampling PLL loop **1910** loses a lock with the phase of the clock signal, the lock detects signal Vld, which is still active, turns low to re-connect the two-way DC switch **1908** to the Digital Phase Frequency Detector **1914** to enable re-locking of the Digital PLL loop **1918** to the clock signal.

In this embodiment, the sampling PLL system **1900** is implemented in an independent chip form, with digital circuits replacing analog functions. The sampling PLL system **1900** may also be implemented as a block on a system on chip (SoC) or as a part of a module. The sampling PLL system **1900** may also be used in the ultra-low phase noise frequency synthesizers **1700** and **1900**.

In this embodiment, the Digital PLL loop **1918** always locks at the correct frequency as the Digital PLL loop **1918** is software controlled to lock at a right frequency. The Digital Phase Frequency Detector **1914** is always able to lock from a distance regardless of how far away initially the VCO **1912** is from the reference clock Fc. Thus, use of the Digital PLL loop **1918** in the sampling PLL system **1900** overcomes the problem of the sampling PLL loop **1916** not being able to lock outside the lock range. The Digital PLL loop **1918** is used to lock the VCO **1912** on the right frequency and then switch to the sampling PLL loop **1916** to achieve the low noise. It also enables the system to operate with a wideband RF VCO **1912** with the assurance that it will lock at the correct frequency. It eliminates the unreliable search mechanism and assures lock under all conditions and temperature conditions by providing true lock detect indication. The presence of Digital Phase Frequency Detector **1914** enables the use of wideband VCO **1912** in the sampling PLL loop **1916**, as the Digital Phase Frequency Detector **1914** is able to lock the VCO **1912** at the desired frequency. The sampling PLL system **1900** offers a significant improvement over other product and is highly useful as one of the most important building blocks for ultra-low noise synthesizers.

In the sampling PLL loop **1916**, there is no digital noise floor and the reference clock Fc determines the overall phase-noise, as this is the only factor that is translated to the output frequency by 20 log N.

Advantages of the sampling PLL system **1900**: a) It enables the sampling PLL **1916** to operate with a wideband RF VCO with assurance that it will lock at the correct frequency, b) It eliminates the unreliable search mechanism

and assures lock under all offset and temperature conditions, c) It provides true lock detect indication, d) Reliable improved operation and performance of the sampling PLL **1916**, e) Ultra-low noise, f) Highly reliable, g) Having vastly improved performance, h) Easy to manufacture and use, i) Operational in a broadband RF range, and j) Implementable in a chip form.

FIG. **20** illustrates an example of a phase-noise simulation plot **2000** contributed by a DDS chip in accordance with the first embodiment of the present invention. The two-dimensional phase-noise simulation plot **2000** comprises of an ordinate (vertical axis) disclosing Phase-noise (dBc/Hz) **2002** and one abscissa (horizontal axis) disclosing Frequency (Hz) **2004**. The phase-noise simulation plot **2000** discloses four phase-noise plots corresponding to four input frequencies which are 1396 MHz **2006**, 696 MHz **2008**, 427 MHz **2010** and 171 MHz **2012** generated by the single DDS chip.

In the first embodiment of the present disclosure as disclosed above in FIG. **17**, the DDS **1702** element generates at least one clock signal Fc**2** of a variable frequency range of 0.1 GHz to 0.225 GHz. Correlating this variable frequency range of 0.1 GHz to 0.225 GHz applicable in the first embodiment of the present disclosure with the DDS phase-noise simulation plot **2000**, it becomes evidently clear that even in worst case scenario the DDS phase-noise contribution in the first embodiment of the present disclosure stays in between the 427 MHz **2010** and the 171 MHz **2012** which is in between −125 dBc/Hz and −120 dBc/Hz which is really very low.

FIG. **21** illustrates a phase-noise simulation plot **2100** contributed by the main PLL **1710** in accordance with the first embodiment of the present disclosure. The two-dimensional phase-noise simulation plot **2100** comprises of an ordinate (vertical axis) disclosing Phase-noise (dBc/Hz) **2102** and one abscissae (horizontal axis) disclosing Frequency (Hz) **2104**. The phase-noise simulation plot **2100** discloses the phase-noise contributed by the main PLL **1710** as disclosed in the first embodiment of the present disclosure in FIG. **17**. It is evidently visible that the phase-noise simulation plot **2100** has multiple contributors. The two most important contributors of phase-noise in the phase-noise simulation plot **2100** are the primary VCO **1706** and the DDS **1702** as discussed in FIG. **17**.

A phase-noise plot **2108** is the contribution of the primary VCO **1706** in the phase-noise simulation plot **2100**. As the primary VCO **1706** belongs to the main PLL **1710**, the main PLL **1710** attenuates the phase-noise **2108** coming from the primary VCO **1706** to quite an extent. This attenuation is clearly visible in the phase-noise simulation plot **2100**.

The other primary contributor in the phase-noise simulation plot **2100** is the phase-noise coming from the DDS **1702** present in the first embodiment of the present disclosure. A phase-noise plot **2112** is the contribution of the DDS **1702** into the main PLL **1710**. The phase-noise plot **2112** is titled as XTAL in the phase-noise simulation plot **2100**. This phase-noise plot **2112** is the contribution of the DDS **1702** in the main PLL **1710** at the worst point of an output frequency of 1000 MHz

The main PLL **1710** forwards the primary VCO **1706** generated output frequencies of 9.5 GHz-9.625 GHz towards the down-convert mixer **1716**. The down-convert mixer **1716** mixes incoming the primary VCO **1706** generated output frequencies of 9.5 GHz-9.6257 GHz with the sampling reference frequency of 9.4 GHz and generates attenuated intermediate frequencies of 0.1 GHz to 0.225 GHz. This attenuation procedure itself reduces the phase noise contributions coming from the primary VCO **1706** and the DDS **1702**. It can be further note that a phase detector noise floor plot **2114** is negligible.

FIG. **22** illustrates a phase-noise simulation plot **2200** contributed by a reference sampling PLL when a TCXO clock (or another reference clock) generates input frequencies of 100 MHz in accordance with the first embodiment of the present disclosure.

The two-dimensional phase-noise simulation plot **2200** comprises of an ordinate (vertical axis) disclosing Phase-noise (dB c/Hz) **2202** and one abscissae (horizontal axis) disclosing Frequency (Hz) **2204**. The phase-noise simulation plot **2200** discloses the phase-noise contributed by the reference sampling PLL **1718** as disclosed in the first embodiment of the present disclosure in FIG. **17**. It is evidently visible that the phase-noise simulation plot **2200** has multiple contributors. The two most important contributors to phase-noise in the phase-noise simulation plot **2200** are the reference VCO **1720** and the reference clock TCXO **1724** as discussed in FIG. **17**.

A phase-noise plot **2208** is the contribution of the reference VCO **1720** in the phase-noise simulation plot **2200**. The reference sampling PLL **1718** attenuates the phase-noise plot **2208** coming from the primary VCO **1706** to quite an extent. This attenuation is clearly visible in the phase-noise simulation plot **2200**.

The other primary contributor in the phase-noise simulation plot **2200** is the phase-noise coming from the reference clock TCXO **1724** present in the first embodiment of the present disclosure. A phase-noise plot **2210** is the contribution of the TCXO **1724** into the reference sampling PLL **1718**. The phase-noise plot **2210** is titled as XTAL in the phase-noise simulation plot **2200**. This phase-noise plot **2210** is the contribution of the TCXO **1724** in the reference sampling PLL **1718**, when the TCXO **1724** is generating input frequencies of 100 MHz

The reference sampling PLL **1718** forwards the generated sampling reference frequency of 9.4 GHz towards the down-convert mixer **1716**. The down-convert mixer **1716** mixes this generated sampling reference frequency of 9.4 GHz with the incoming frequencies of 9.5 GHz-9.625 GHz to generate an attenuated intermediate frequency of 0.1 GHz to 0.225 GHz. This attenuation procedure itself reduces the phase-noise contributions coming from the reference VCO **1720** and the TCXO **1724**.

FIG. **23** illustrates a phase-noise simulation plot **2300** contributed by a reference sampling PLL when a TCXO clock (or another reference clock) generates input frequencies of 250 MHz in accordance with the first embodiment of the present disclosure.

The two-dimensional phase-noise simulation plot **2300** comprises of an ordinate (vertical axis) disclosing Phase-noise (dBc/Hz) **2302** and one abscissae (horizontal axis) disclosing Frequency (Hz) **2304**. The phase-noise simulation plot **2300** discloses the phase-noise contributed by the reference sampling PLL **1718** as disclosed in the first embodiment of the present disclosure in FIG. **17**. It is evidently visible that the phase-noise simulation plot **2300** has multiple contributors. The two most important contributors to phase-noise in the phase-noise simulation plot **2300** are the reference VCO **1720** and the TCXO **1724** as discussed in FIG. **17**.

A phase-noise plot **2308** is the contribution of the reference VCO **1720** in the phase-noise simulation plot **2300**. The reference sampling PLL **1718** attenuates the phase-

noise plot **2308** coming from the primary VCO **1706** to quite an extent. This attenuation is clearly visible in the phase-noise simulation plot **2300**.

The other primary contributor in the phase-noise simulation plot **2300** is the phase-noise coming from the TCXO **1724** present in the first embodiment of the present invention. A phase-noise plot **2310** is the contribution of the TCXO **1724** into the reference sampling PLL **1718**. The phase-noise plot **2310** is titled as XTAL in the phase-noise simulation plot **2300**. This phase-noise plot **2310** is the contribution of the TCXO **1724** in the reference sampling PLL **1718**, when the TCXO **1724** is generating input frequencies of 250 MHz

The reference sampling PLL **1718** forwards the generated sampling reference frequency of 9.4 GHz towards the down-convert mixer **1716**. The down-convert mixer **1716** mixes this generated sampling reference frequency of 9.4 GHz with the incoming frequencies of 9.5 GHz-9.625 GHz to generate attenuated intermediate frequencies of 0.1 GHz to 0.225 GHz. This attenuation procedure itself reduces the phase-noise contributions coming from the reference VCO **1720** and the TCXO **1724**.

FIG. **24** illustrates a phase-noise simulation plot **2400** contributed by the main PLL in accordance with the second embodiment of the present disclosure. The two-dimensional phase-noise simulation plot **2400** comprises of an ordinate (vertical axis) disclosing Phase-noise (dBc/Hz) **2402** and one abscissae (horizontal axis) disclosing Frequency (Hz) **2404**. The phase-noise simulation plot **2400** discloses the phase-noise contributed by the main PLL **1812** as disclosed in the second embodiment of the present disclosure in FIG. **18**. The primary difference between the phase-noise simulation plot **2400** and the above plots of FIGS. **21**, **22** and **23** is that there is no DDS present in the second embodiment of the present disclosure. The most important contributor of phase-noise in the phase-noise simulation plot **2400** is the TCXO **1802** as discussed in FIG. **18**.

A phase-noise plot **2412** is the contribution of the TCXO **1802** into the main PLL **1810**. The phase-noise plot **2412** is titled as XTAL in the phase-noise simulation plot **2400**. Due to the absence of a DDS in the second embodiment of the present invention, a phase detector plot **2410** becomes a major factor.

The main PLL **1812** forwards the primary VCO **1810** generated output frequencies of 9.5 GHz-9.625 GHz towards the down-convert mixer **1816**. The down-convert mixer **1816** mixes incoming the primary VCO **1810** generated output frequencies of 9.5 GHz-9.625 GHz with the sampling reference frequency of 9.4 GHz and generates attenuated intermediate frequencies of 0.1 GHz to 0.225 GHz. This attenuation procedure itself reduces the phase-noise contributions coming from the TCXO **1802**.

FIG. **25** illustrates a phase-noise simulation plot **2500** contributed by a reference sampling PLL having the TCXO clock generating input frequencies of 100 MHz in accordance with the second embodiment of the present disclosure. The two-dimensional phase-noise simulation plot **2500** comprises of an ordinate (vertical axis) disclosing Phase-noise (dBc/Hz) **2502** and one abscissae (horizontal axis) disclosing Frequency (Hz) **2504**. The phase-noise simulation plot **2500** discloses the phase-noise contributed by the reference sampling PLL **1818** as disclosed in the second embodiment of the present disclosure in FIG. **18**.

The primary contributor to the phase-noise simulation plot **2500** is the phase-noise coming from the TCXO **1802** present in the second embodiment of the present disclosure. A phase-noise plot **2510** is the contribution of the TCXO **1802** into the reference sampling PLL **1818**. The phase-noise plot **2510** is titled as XTAL in the phase-noise simulation plot **2500**. This phase-noise plot **2510** is the contribution of the TCXO **1802** in the reference sampling PLL **1818**, when the TCXO **1802** is generating input frequencies of 100 MHz

The reference sampling PLL **1818** forwards the generated sampling reference frequency of 9.4 GHz towards the down-convert mixer **1716**. The down-convert mixer **1816** mixes this generated sampling reference frequency of 9.4 GHz with the incoming frequencies of 9.5 GHz-9.625 GHz to generate a attenuated intermediate frequencies of 0.1 GHz to 0.225 GHz.

FIG. **26** illustrates a phase-noise simulation plot **2600** contributed by a reference sampling PLL having the TCXO clock (or another reference clock) generating input frequencies of 250 MHz in accordance with the second embodiment of the present disclosure.

The two-dimensional phase-noise simulation plot **2600** comprises of an ordinate (vertical axis) disclosing Phase-noise (dBc/Hz) **2502** and one abscissae (horizontal axis) disclosing Frequency (Hz) **2504**. The phase-noise simulation plot **2600** discloses the phase-noise contributed by the reference sampling PLL **1818** as disclosed in the second embodiment of the present disclosure in FIG. **18**.

The primary contributor to the phase-noise simulation plot **2600** is the phase-noise coming from the TCXO **1802** present in the second embodiment of the present disclosure. A phase-noise plot **2610** is the contribution of the TCXO **1802** into the reference sampling PLL **1818**. The phase-noise plot **2610** is titled as XTAL in the phase-noise simulation plot **2600**. This phase-noise plot **2610** is the contribution of the TCXO **1802** in the reference sampling PLL **1818**, when the TCXO **1802** is generating input frequencies of 250 MHz.

The reference sampling PLL **1818** forwards the generated sampling reference frequency of 9.4 GHz towards the down-convert mixer **1716**. The down-convert mixer **1816** mixes this generated sampling reference frequency of 9.4 GHz with the incoming frequencies of 9.5 GHz-9.625 GHz to generate a attenuated intermediate frequencies of 0.1 GHz to 0.225 GHz.

FIG. **27** illustrates a flow chart **2700** depicting the operational methods of the first embodiment in accordance with the present disclosure. At step **2702**, the Reference Sampling PLL receives clock signals from a TCXO, generates sampling frequencies to eliminate digital noise floor and forwards the sampling frequencies towards a Down Convert Mixer.

At step **2704**, the Main PLL receives clock signals from a low noise frequency generator DDS, generates the output frequencies and forwards them towards the Down Convert Mixer.

At step **2706**, the Down Convert Mixer which is a part of the Main PLL receives frequencies coming from both the Main PLL and the Reference Sampling PLL, mixes them to reduce a multiplication number N to achieve high data rate, high modulation schemes and low phase deviation errors.

FIG. **28** illustrates a flow chart **2800** depicting the operational methods of the second embodiment in accordance with the present disclosure. At step **2802**, the Reference Sampling PLL receives clock signals from a TCXO (or another reference clock), generates sampling frequencies to eliminate digital noise floor and forwards the sampling frequencies towards a Down Convert Mixer.

At step **2804**, the Main PLL receives clock signals from the same TCXO, generates the output frequencies and forwards them towards the Down Convert Mixer.

At step **2806**, the Down Convert Mixer which is a part of the Main PLL receives frequencies coming from both the Main PLL and the Reference Sampling PLL, mixes them to reduce a multiplication number N to achieve high data rate, high modulation schemes and low phase deviation errors.

FIG. **29** illustrates a flow chart **2900** depicting the operational methods of the third embodiment in accordance with the present disclosure. At step **2902**, a TCXO generates a clock signal of the low noise of one frequency that can be anywhere between 100 MHz to 250 MHz

At step **2904**, a Sampling Phase Detector receives the clock signals and eliminates digital noise floor.

At step **2906**, a Digital PLL is added with the Sampling PLL to improve performance and reliability of an Ultra-Low Phase-noise Frequency Synthesizer to achieve high data rates, high modulation schemes and low phase deviation errors.

In one embodiment of the invention the ultra-low phase noise frequency synthesizer comprises at least one sampling Phase Locked Loop (PLL), wherein the at least one sampling PLL comprises:

a. at least one reference clock configured to generate at least one first clock signal of at least one first clock frequency;

b. at least one sampling phase detector configured to receive the at least one first clock signal and a single reference frequency to generate at least one first analog control voltage;

c. a Digital Phase/Frequency detector configured to receive the at least one first clock signal and a single reference frequency to generate at least a second analog control voltage; and

d. at least one reference Voltage Controlled Oscillator (VCO) configured to receive the at least one analog control voltage to generate the single reference frequency;

Further, in one embodiment of the invention the ultra-low phase noise frequency synthesizer configured to determine phase noise and quality of at least one sampling Phase Locked Loop (PLL), wherein the at least one sampling PLL comprises:

a. at least one reference clock configured to generate at least one first clock signal of at least one first clock frequency;

b. at least one sampling phase detector configured to receive the at least one first clock signal and a single reference frequency to generate at least one first analog control voltage;

c. a Digital Phase/Frequency detector configured to receive the at least one first clock signal and a single reference frequency to generate at least a second analog control voltage; and

d. at least one reference Voltage Controlled Oscillator (VCO) configured to receive the at least one analog control voltage to generate the single reference frequency;

Furthermore, in one embodiment of the invention A system for detecting the surrounding environment of a vehicle comprising at least first sensor, configured to obtain data, the at least first sensor comprising a transmitter for transmitting at least one radio signal to the one or more objects within the surrounding environment. Further, the first sensor may include a receiver for receiving the at least one radio signal returned from the one or more objects. Furthermore, the first sensor may include at least one ultra-low phase noise frequency synthesizer configured to determine phase noise and quality of the transmitted and the received at least one radio signal, wherein the at least one ultra-low phase noise frequency synthesizer comprises at least one sampling Phase Locked Loop (PLL), at least one main PLL. Further, the system may include a processing unit. The processing unit coupled to the at least first sensor configured to gather electro-magnetic information about the one or more objects. Further, the processing unit may classify or recognize each of the one or more objects by analyzing the data, wherein the classification or recognition is based on a unique signature obtained from each of the one or more objects. Furthermore, the processing unit may generate an electromagnetic map of the surrounding environment by utilizing unique signatures of the one or more objects. Again further, the processing unit may combine the electromagnetic map with a geographical map or physical map.

In one embodiment of the invention ultra-low phase noise frequency synthesizer comprises at least one sampling Phase Locked Loop (PLL) and at least one main PLL. The at least one main PLL comprises at least one Fractional-N synthesizer, wherein the at least one Fractional-N synthesizer comprises:

a. at least one high frequency Digital Phase/Frequency detector configured to receive and compare the at least one clock frequency and at least one feedback frequency to generate the at least one second analog control voltage and at least one digital control voltage; and

b. at least one variable frequency divider configured to divide at least one intermediate signal by a predetermined factor N to generate at least one feedback signal of the at least one feedback frequency.

Yet, in another embodiment of the invention the system for detecting the surrounding environment of a vehicle comprising:

at least first sensor, configured to obtain data, the at least first sensor comprising

A) a transmitter for transmitting at least one radio signal to the one or more objects within the surrounding environment;

B) a receiver for receiving the at least one radio signal returned from the one or more objects;

C) at least one ultra-low phase noise frequency synthesizer configured to determine phase noise and quality of the transmitted and the received at least one radio signal, wherein the at least one ultra-low phase noise frequency synthesizer comprises:

1) at least one sampling Phase Locked Loop (PLL), wherein the at least one sampling PLL comprises:

a. at least one reference clock configured to generate at least one first clock signal of at least one first clock frequency;

b. at least one sampling phase detector configured to receive the at least one first clock signal and a single reference frequency to generate at least one first analog control voltage;

c. a Digital Phase/Frequency detector configured to receive the at least one first clock signal and a single reference frequency to generate at least a second analog control voltage; and

d. at least one reference Voltage Controlled Oscillator (VCO) configured to receive the at least one analog control voltage to generate the single reference frequency;

2) at least one main PLL, wherein the at least one main PLL comprises:

a. at least one first fixed frequency divider configured to receive the at least one reference frequency and to divide the at least one reference frequency by a first predefined factor to generate at least one Direct Digital Synthesizer (DDS) clock signal;

b. at least one high frequency DDS configured to receive the at least one DDS clock signal and to generate at least one second clock signal of at least one second clock frequency;

c. at least one high frequency Digital Phase/Frequency detector configured to receive and compare the at least one second clock frequency and at least one feedback frequency to generate at least one second analog control voltage and at least one digital control voltage;

d. at least one main VCO configured to receive the at least one first analog control voltage or the at least one second analog control voltage and generate at least one output signal of at least one output frequency, wherein the at least one digital control voltage controls which of the at least one first analog control voltage or the at least one second analog control voltage is received by the at least one main VCO;

e. at least one down convert mixer configured to mix the at least one output frequency and the reference frequency to generate at least one intermediate frequency; and

f. at least one second fixed frequency divider configured to receive and divide the at least one intermediate frequency by a second predefined factor to generate the at least one feedback frequency;

3) a processing unit, coupled to the at least first sensor configured to;

a. gather, electro-magnetic information about the one or more objects;

b. classify or recognize each of the one or more objects by analyzing the data, wherein the classification or recognition is based on a unique signature obtained from each of the one or more objects;

c. generate an electromagnetic map of the surrounding environment by utilizing unique signatures of the one or more objects; and

d. combine the electromagnetic map with a geographical map or physical map.

In an embodiment of the invention the RADAR sensor transmits, receives, and process radio frequency signals that detects data includes information about the electromagnetic properties and characteristics of the objects of interest or the surroundings of the vehicle. The data may include shape, silhouette, doppler or micro doppler information. The data may include depth, dimensions, direction, height, distance and placement of the object of interest with respect to the vehicle.

The signal processing or the computation of such information and data may include detecting and classification the type of the one or more objects includes living or non-living thing, stationary or moving object, animal or human, standing or mobile human, metal, wood, or concrete.

In one embodiment of the invention a system for detecting the surrounding environment of a vehicle comprising: AA) at least first sensor, configured to obtain data, the at least first sensor comprising:

A) a transmitter for transmitting at least one radio signal to the one or more objects within the surrounding environment;

B) a receiver for receiving the at least one radio signal returned from the one or more objects;

C) at least one ultra-low phase noise frequency synthesizer configured to determine phase noise and quality of the transmitted and the received at least one radio signal, wherein the at least one ultra-low phase noise frequency synthesizer comprises:

1) at least one sampling Phase Locked Loop (PLL), wherein the at least one sampling PLL comprises:

a. at least one reference clock configured to generate at least one first clock signal of at least one first clock frequency;

b. at least one sampling phase detector configured to receive the at least one first clock signal and a single reference frequency to generate at least one first analog control voltage;

c. a Digital Phase/Frequency detector configured to receive the at least one first clock signal and a single reference frequency to generate at least a second analog control voltage; and

d. at least one reference Voltage Controlled Oscillator (VCO) configured to receive the at least one analog control voltage to generate the single reference frequency;

2) at least one main PLL, wherein the at least one main PLL comprises:

a. at least one Fractional-N synthesizer, wherein the at least one Fractional-N synthesizer comprises:

i. at least one high frequency Digital Phase/Frequency detector configured to receive and compare the at least one clock frequency and at least one feedback frequency to generate the at least one second analog control voltage and at least one digital control voltage; and

ii. at least one variable frequency divider configured to divide at least one intermediate signal by a predetermined factor N to generate at least one feedback signal of the at least one feedback frequency;

BB) a processing unit, coupled to the at least first sensor configured to:

a. gather, electro-magnetic information about the one or more objects;

b. classify or recognize each of the one or more objects by analyzing the data, wherein the classification or recognition is based on a unique signature obtained from each of the one or more objects;

c. generate an electromagnetic map of the surrounding environment by utilizing unique signatures of the one or more objects; and

d. combine the electromagnetic map with a geographical map or physical map.

In one embodiment of the invention a system for detecting the surrounding environment of a vehicle comprising at least first sensor. The first sensor may be configured to obtain data. The at least first sensor comprising:

A) a transmitter for transmitting at least one radio signal to the one or more objects within the surrounding environment;

B) a receiver for receiving the at least one radio signal returned from the one or more objects;

C) at least one ultra-low phase noise frequency synthesizer configured to determine phase noise and quality of the transmitted and the received at least one radio signal, wherein the at least one ultra-low phase noise frequency synthesizer comprises:

1) at least one sampling Phase Locked Loop (PLL), wherein the at least one sampling PLL comprises:
a. at least one reference clock configured to generate at least one first clock signal of at least one first clock frequency;
b. at least one sampling phase detector configured to receive the at least one first clock signal and a single reference frequency to generate at least one first analog control voltage;
c. a Digital Phase/Frequency detector configured to receive the at least one first clock signal and a single reference frequency to generate at least a second analog control voltage; and
d. at least one reference Voltage Controlled Oscillator (VCO) configured to receive the at least one analog control voltage to generate the single reference frequency.

Further, the system for detecting the surrounding environment of the vehicle comprises a processing unit, coupled to the at least first sensor configured to;

a. gather, electro-magnetic information about the one or more objects;
b. classify or recognize each of the one or more objects by analyzing the data, wherein the classification or recognition is based on a unique signature obtained from each of the one or more objects;
c. generate an electromagnetic map of the surrounding environment by utilizing unique signatures of the one or more objects; and
d. combine the electromagnetic map with a geographical map or physical map.

Yet, in another embodiment of the invention a method for detecting the surrounding environment of a vehicle comprising:

AA) at least first sensor, configured to obtain a data, the at least first sensor comprising

A) a transmitter for transmitting at least one radio signal to the one or more objects within the surrounding environment;
B) a receiver for receiving the at least one radio signal returned from the one or more objects;
C) at least one ultra-low phase noise frequency synthesizer configured to determine phase noise and quality of the transmitted and the received at least one radio signal, wherein the at least one ultra-low phase noise frequency synthesizer comprises:
1) at least one sampling Phase Locked Loop (PLL), wherein the at least one sampling PLL comprises:
a. at least one reference clock configured to generate at least one first clock signal of at least one first clock frequency;
b. at least one sampling phase detector configured to receive the at least one first clock signal and a single reference frequency to generate at least one first analog control voltage;
c. a Digital Phase/Frequency detector configured to receive the at least one first clock signal and a single reference frequency to generate at least a second analog control voltage; and
d. at least one reference Voltage Controlled Oscillator (VCO) configured to receive the at least one analog control voltage to generate the single reference frequency;
2) at least one main PLL, wherein the at least one main PLL comprises:
a. at least one first fixed frequency divider configured to receive the at least one reference frequency and to divide the at least one reference frequency by a first predefined factor to generate at least one Direct Digital Synthesizer (DDS) clock signal;
b. at least one high frequency DDS configured to receive the at least one DDS clock signal and to generate at least one second clock signal of at least one second clock frequency;
c. at least one high frequency Digital Phase/Frequency detector configured to receive and compare the at least one second clock frequency and at least one feedback frequency to generate at least one second analog control voltage and at least one digital control voltage;
d. at least one main VCO configured to receive the at least one first analog control voltage or the at least one second analog control voltage and generate at least one output signal of at least one output frequency, wherein the at least one digital control voltage controls which of the at least one first analog control voltage or the at least one second analog control voltage is received by the at least one main VCO;
e. at least one down convert mixer configured to mix the at least one output frequency and the reference frequency to generate at least one intermediate frequency; and
f. at least one second fixed frequency divider configured to receive and divide the at least one intermediate frequency by a second predefined factor to generate the at least one feedback frequency;

BB) a processing unit, coupled to the at least first sensor configured to:

a. gathering, electro-magnetic information about the one or more objects;
b. classifying or recognize each of the one or more objects by analyzing the data, wherein the classification or recognition is based on a unique signature obtained from each of the one or more objects;
c. generating an electromagnetic map of the surrounding environment by utilizing unique signatures of the one or more objects; and
d. combining the electromagnetic map with a geographical map or physical map.

In one embodiment of the invention discloses a method of further comprising recognizing the object on interest after classifying, wherein the classification of the object of interest includes living or non-living thing, stationary or moving object, animal or human, standing or mobile human, metallic, wooden, or concrete objects.

FIG. **30**A illustrates a "dead zone" within immediate surroundings of a LiDAR.

FIG. **30**B illustrates a LiDAR mounted over the top of a vehicle, in order to eliminate the "dead zone" as much as possible. These limits the options of using parking garages, causes difficulty in the use of rooftop accessories and finally also makes the vehicle less marketable since such a tower does not blend in well with the design of a vehicle.

FIG. **31** illustrates non-reliability of a LiDAR in adverse weather such as rain, fog, and snow. LiDAR systems use mechanical rotation mechanisms that are prone to failure.

Typical LiDAR systems rely on a rotation speed of around 5-15 Hz. This means that if a vehicle moves at a speed of 65 mph, the distance the vehicle travels between "looks" is about 10 ft. RADAR sensor systems are able to continuously scan their surroundings especially when these systems use one transmitting and one receiving antenna (Bistatic system)

(as depicted in FIG. **32**A). Further, LiDAR systems are not accurate in determining the speed and autonomous vehicles rely on RADAR for accurate speed detection.

FIG. **32**B illustrates the effect of phase-noise in the distance and angular resolution of the RADAR. The clutter to noise ratio (CNR) in a standard RADAR, as shown in the figure, restricts the longer distance resolution and the angular resolution. This results in non-identification of smaller objects present on the road. Also, the CNR restricts the range of the RADAR that may be distance or angular range.

FIG. **32**C illustrates resolution problem with RADAR signals. The RADAR signals, due to high phase-noise are not able to distinguish between closely placed objects and slow-moving objects nor can the object be imaged correctly, or its electrical characteristics determined with sufficient reliability. Due to the high phase-noise, vehicles may not have a clear picture of what is in-front or surrounding them. RADAR systems may give wrong and/or error-prone readings. This happens due to the lesser resolution characteristics. Phase-noise plays a crucial role in the resolution which has been determined clearly in the prior art. Due to this low-resolution characteristic, the objects close to the vehicle and slowly moving are not properly distinguished. As seen, in the figure, the correct position of the vehicle in-front may not be accurately ascertained and may give blurry or multiple appearances. Also, as shown in the figure, very closely placed objects like two people close by may be read as a single object. Hence, for close objects, there is no differentiation.

FIG. **33** depicts usage of available light to determine the surroundings of an autonomous vehicle.

Further, in old-fashioned Radars, the Doppler effect gets a little more complicated since a Radar is sending out a signal and expects to a received signal that is lower in power but at the same frequency when it hits an object. If this object is moving, then this received signal will be subject to the Doppler effect and in reality, the received signal will not be received at the same frequency as the frequency of the transmit signal. The challenge here is that these frequency errors can be very subtle and could be obscured by the phase-noise of the system (as shown in FIG. **34**). The obvious drawback is that vital information about the velocity of an object gets lost only because of phase-noise (see figure below). The above is especially right when dealing with objects that move slower than airplanes and missiles, such as cars, bicycles, pedestrians, etc.

Further, the spectral picture of a processed signal looks like the FIG. **35**. As one can see the spectral picture contains also unwanted side lobes. One major contributor to the side lobes is the phase-noise of the Radar system. This spectral regrowth of side lobes can cause errors in the determination of the actual distance of a target and can obscure a small target that is close to a larger target. It can also cause errors in target velocity estimation. As shown in FIG. **36**, weaker return signals can get obscured in the side lobes of a stronger signal.

FIG. **37** illustrates a detection system **3700**, in accordance with various embodiments of the present invention. The detection system includes, but not limited to, a RADAR unit **3702**, an ultra-lowphase-noise frequency synthesizer **3704**, a memory **3706** and a specialized processor **3708**. The RADAR unit **3702** may be configured for detecting the presence of one or more objects/targets in one or more directions by transmitting radio signals in the one or more directions. In an embodiment, the RADAR unit **3702** may be comprised of at least one of or combination of: a traditional RADAR system, a synthetic aperture RADAR, or a type of RADAR with a number of RADAR subsystems and antennas. Further, the RADAR unit may include a transmitter for transmitting at least one radio signal with the goal of receiving a received signal; from one or more objects.

The ultra-lowphase-noise frequency synthesizer **3704** (hereinafter may interchangeably be referred to as 'frequency synthesizer **3704**') may be providing the needed carrier frequency, or a multiple or a fraction of the needed carrier (or up-conversion) frequency for the RADAR transmitter section. The ultra-low noise frequency synthesizer **3704** may also be providing the needed carrier (or down-conversion) frequency, or a multiple or a fraction of the needed carrier frequency for the RADAR receiver section. For some RADARs the transmit signal is used as the carrier frequency for the receive section, this does not alter the principle of this invention and is merely another form of implementation. The term "carrier" may be used interchangeably referring to an up-conversion or down-conversion signal.

The output of the frequency synthesizer **3704** may include a continuous wave signal with ultra-lowphase-noise. The received radio signal may be down-converted with the help of frequency synthesizer **3704** and analyzed to determine information and/or characteristics corresponding to the one or more objects. Such information may include (but not limited to) velocity, distance, frequency and type(s) of the object(s). The distance may be determined between the object and the RADAR unit **3702**. Accordingly, an action may be adopted by the system **3700** based on the information received from the analysis of the synthesized radio signal. For example, if the detection system **3700** is implemented in a vehicle, the RADAR unit **3702** may transmit the radio signals, that in this case will carry ultra-low or negligible phase-noise and following that the received return signal will carry ultra-low or negligible phase-noise as well. The return signal will be analyzed to determine the presence of the objects and their locations with respect to the vehicle. The fact that an ultra-low phase-noise synthesizer is used practically guarantees that the information corresponding to the one or more objects may be determined in a more accurate fashion than for traditional RADAR systems and thus, accordingly, a correct decision may be taken based on execution of the instructions set by the processor **3708**.

Further, in case of a RADAR unit, the received signal (i.e., received from hitting an object and returning as echo) will be subject to the Doppler effect. A system implemented in autonomous vehicles that utilize the characteristics of the Doppler effect, potential slow-moving targets will create a very small Doppler frequency shift that is very hard to impossible to identify with traditional RADAR systems that do not implement an ultra-low noise synthesizer. As a result of the much-improved phase-noise at low-offset frequencies from the carrier, such signals have a significantly better chance to be detected and analyzed correctly. Further, the traditional method of analysis does not need to change and should also not change the amount of data produced by the analysis, it will, however—improve the accuracy of the information created by the RADAR system.

The memory **3706** may include instructions set **3710** having one or more specialized instructions and a database **3712**. The specialized instructions may be executable by the specialized processor **3708**. The detection system **3700** may receive an input from an external source (not shown). Such input may be provided to activate the detection system **3700**. The input may be a command that may be provided through an input source such as a keyboard or a switch. Further, the input may be provided remotely to the detection system

3700 that may be processed by the processor 3708 in accordance with the instructions set 3710. In an embodiment, once the input is received by the system 3700, the transmitter of the RADAR unit 3702 may initiate transmitting the radio waves in multiple directions. For example, the radio waves may be transmitted everywhere in 360 degrees to determine the presence of one or more objects.

In an embodiment, the RADAR unit 3702 of the detection system 3700 may be placed above the vehicle, or anywhere else in or on the vehicle, to transmit the radio signals in various directions and further to receive the returned radio signals as returned from the object(s) (after hitting the object(s)).

Further, the specialized instruction on execution by the specialized processor gathers information corresponding to the one or more objects and surroundings corresponding thereto, the information being gathered based on the returned radio signal. Specifically, the information corresponding to the object may be gathered from the radio signal that is returned from the object(s). The information gathered may include, but is not limited to, surrounding information of the object(s) such as road structure, traffic in front of those objects, traffic behavior, the response of the one or more objects based on the traffic behavior. Further, based on analysis of these, the system may determine probable next move corresponding to the one or more objects and perform pre-planning corresponding to probable moves that may be required in near future. Such intelligent planning of the detection system may determine probable events on the road. This further ensures safety on the road. Further, the information corresponding to the objects and surrounding may be stored in the database 3712 for future reference and planning. Furthermore, the information may be provided to an output device (not shown) such as a display. The information may also be transferred to a Database outside of the autonomous vehicle such as, but not limited to, a cloud-based database.

With the implementation of the ultra-low phase-noise frequency synthesizers 3704, the improved phase noise translated to degrees is better than 0.04 degrees. The detection system is further explained with an illustration in conjunction with the following figure(s) (i.e., FIG. 38).

FIG. 38 illustrates an exemplary vehicle 3800 implementing a detection system (such as the detection system 3700), in accordance with an embodiment of the present invention. The RADAR unit 3802 of the detection system may be configured anywhere inside or outside the vehicle 3800. For example, as depicted, the RADAR unit 3802 is placed on the top of the vehicle to detect the presence of one or more objects in one or more directions. Such objects may include, but is not limited to, other vehicles, human, animal, flying objects or other types of objects in the surroundings. Further, the objects may be of varying size and type and may have different characteristics that may be determined by the RADAR unit. Herein, the characteristics of objects may include, but not limited to, shape, size, running speed, maximum possible speed (for example, based on the type of the vehicle) and so on. In an embodiment, the RADAR unit 3802 may be positioned at another place such as outside or inside the vehicle.

Further, the RADAR unit 3802 may include a transmitter for transmitting radio signals created in conjunction with an implementation of an ultra-low phase-noise synthesizer. This signal is transmitted with the goal to be echoed back (returned radio signal) from one or more objects (that may be available in the surrounding or other near areas). Further, the RADAR unit 3802 may include a receiver for receiving the returned radio signal generated by its paired transmitter or another transmitter from the one or more objects. As depicted, signals 3804 may be transmitted and received by the RADAR unit 3802.

In an embodiment, the ultra-lowphase-noise frequency synthesizer (hereinafter may interchangeably be referred to as 'frequency synthesizer 3704') may be configured inside the vehicle 3800 that may be coupled to the radio unit 3802 positioned on outside surface of the vehicle. In an alternate embodiment, the frequency synthesizer 3704 may be configured on outside surface of the vehicle along with the RADAR unit.

Further, the detection system may include a processor for processing of the refined radio signals that may further be analyzed to determine information corresponding to the one or more objects. Further, the processor may determine additional information corresponding to the one or more objects based on the determined information and one or more factors. Such information and additional information may include (but is not limited to) velocity, distance, angular position, frequency and type(s) of the object(s). The distance may be determined between the object and the RADAR unit 3702 and accordingly the expected time by which the object may reach near the vehicle and vice versa may also be determined. Herein, the one or more factors may include (but not limited to) at least one of one or more input instructions, analysis of past history, and current situation.

Further, a suitable action may be determined by the detection system 3700 (for example, by the processor thereof) based on analysis of the refined radio signal. Such determined suitable action may then be performed by the vehicle 3800. For example, the processor (as shown in FIG. 37) may provide signals for actuation of one or more components of the vehicle to perform one or more actions based on the one or more input instructions. In an embodiment, the detection system 3700 may include an input unit for receiving one or more input instructions from an external source (such as a user or device). Such instructions may be stored in a memory (as shown in FIG. 37) of the detection system.

In an embodiment, the objects, such as other vehicles, may also implement the detection system. Further, through the RADAR unit, each object (such as, but not limited to the vehicle) may be able to interact/interact/communicate with other objects through RADAR signals either by utilizing RADAR signals generated by other objects or another form of interaction. Furthermore, the detection system may enable determining location and more characteristics of other objects (such as a vehicle) having the detection system therein.

In an embodiment, the detection system may further be equipped with one or more components and/or sensors to enable additional functioning corresponding thereto. For example, LiDAR, cameras, image processing, and additional sensors may be utilized to create a 3D mapping of the surroundings Further, the object such as a vehicle (having the detection system) may receive instructions from an external source that may be processed effectively by implementing the detection system. For example, if the vehicle (having the detection system) receives instructions to reach a particular place at a remote location. The detection system in combination with GPS may enable the vehicle to reach to such particular place. In an embodiment, the detection system may further utilize one or more cameras that may provide additional information regarding the environment (and the objects therein) to the detection system. Advanta-

geously, this enables self-driving of the vehicle without external guidance from a person (such as a driver).

In another embodiment of the invention, the vehicle **3800** may have more than one RADAR units placed on it. Each RADAR unit may have a separate transmitting and receiving antenna. Inputs from various RADAR units may be accumulated and processed by the processor (to be explained later in the detailed description) to generate a 3-dimensional map of the road traversed by the vehicle **3800**. Inputs may also be taken from various other sensors to determine the correctness of data received.

To facilitate object detection, RADAR **3702** may provide information about the vehicle's (**3800**) environment by generating and transmitting to the environment RADAR signals and measuring the returned signals. A computing device like processor **3708** or system associated may then determine the distances and relative locations of objects using the data provided by the RADAR unit **3702**.

More specifically, to detect an object based on range data received from a RADAR unit **3702** and/or other sensors, a vehicle's computing system may generate a 3D point cloud based on information captured by the sensors. The RADAR unit **3702** and/or another sensor may capture information about objects in the form of data points, which may make up the 3D point cloud. The information associated with the various data points may also be referred to as range data and may provide information related to the position and orientation of objects in the environment relative to the vehicle (e.g., a 3D mapping of the environment). The data points may also enable a computing system to determine materials and other information about objects in the environment.

A point cloud is a set of data points in some coordinate system. Data points within a point cloud may be organized within a 3D coordinate system, which may be defined by an X, Y, and Z coordinates, for example. In addition to providing information relating to distances between objects and the RADAR unit **3702**, the data points may also represent the external surface of an object or multiple objects. Within a point cloud, a computing system may cluster similar points together and fill in the appropriate patterns according to the data points to detect objects within the environment. The computing system may use various techniques to convert a point cloud to a 3D surface. Some approaches, like Delaunay triangulation, alpha shapes, and ball pivoting, build a network of triangles over the existing vertices of the point cloud, while other approaches convert the point cloud into a volumetric distance field and reconstruct the implicit surface so defined through a marching cubes algorithm.

Furthermore, the processor **3708** may analyze the data points within the 3D point cloud (as data points or as determined 3D surfaces) to determine the sizes, positions, and/or orientations of objects in the environment. Likewise, the computing device recognizes objects within a point cloud by clustering data points that correspond to the same object and may also determine the materials of the object based on the reflections of the data points on the various objects.

However, using clustering techniques to identify specific objects within information formatted into a 3D point cloud may require substantial amounts of time and/or processing power. Further, an object of interest may not be identified using clustering techniques due to the layout and/or positioning of the object within the environment. For example, a computing system may not be able to detect a pedestrian standing in front of a tree or vehicle within a 3D point cloud because point clustering may cluster and identify the pedestrian and the other object as a single object, which thus has an unknown shape. The processor **3708** may need to perform multiple iterations of analysis to separate and identify the pedestrian from the other object during the 3D point cloud analysis. Thus, while formatting RADAR data in a 3D point cloud may allow a computing device to identify objects in some instances, the computing device may need to devote more resources (e.g., time/power) to accurately scan and identify objects within the cloud. The example implementations discussed may help to overcome some of the deficiencies that can arise during the execution of traditional clustering techniques.

For instance, in an example embodiment, a vehicle's computing system may generate a spherical data set based on the range data gathered from the RADAR unit **3702** or other vehicle sensors. Generating the spherical data set may involve the processor projecting the RADAR return signal into spherical coordinates or some other useful format. A spherical coordinate system may be represented as a coordinate system for three-dimensional space, where the position of a point is specified by three numbers: the radial distance of the point from a fixed origin, its polar angle measured from a fixed zenith direction, and the azimuth angle of its orthogonal projection on a reference plane that passes through the origin and is orthogonal to the zenith, measured from a fixed reference direction on that plane. Other coordinate-based systems may be used as well.

FIG. **39** illustrates RADAR **3702** and its various components, in accordance with an embodiment of the invention. The RADAR **3702** includes a synchronizer **37022**, a power supply **37024**, a transmitter **37026**, a receiver **37030**, an RF Power divider **37028**, and an antenna **37032**.

The synchronizer **37022**, synchronizes signal generation for the RADAR **3702**. The synchronizer **37022**, may include a clock to perform this functionality. This helps the RADAR **3702** to generate signals pulses at equal intervals of time maintaining the intervals of the time constant. The specific function of the synchronizer is to produce TRIGGER PULSES that start the transmitter, indicator sweep circuits, and ranging circuits.

Power supply **37024**, provides power to various components within the RADAR unit **3702**.

The RF Power Divider **37028**, provides the TX signal to the receiver, where it may be used as Local Oscillator for down-conversion to a baseband signal. When a single antenna is used for both transmission and reception, as in most monostatic radar systems, the Power divider **37028** must be used. In high power Radar systems, the Power divider may be implemented as an Isolator or RF coupler to protect the receiver from the high power output of the transmitter. In low power RADAR systems, a Power divider may be sufficient.

The transmitter **37026**, performs various important functions. The functions include the creation of radio waves to be transmitted, conditions the wave to form the pulse train, and amplifies the signal to a high-power level to provide adequate range.

The receiver **37030**, receives the signals when returned by hitting the objects. The receiver **37028** detect wanted echoes in the received signal in the presence of noise, clutter, and interference; and amplifies the desired signals for subsequent processing.

The generated signals are generated and returned signals are received using the antenna **37032**. The transmitter **37026** and the receiver **37030** may use a single antenna. Such a construction is known as monostatic RADAR unit. However, in other embodiment, the transmitter **37026** and the receiver **37030** may utilize different antennae. In such

RADAR units, Power divider **37028** may be eliminated. Such a construction is known as bi-static RADAR unit. This concept is not limited to only one transmitter and one receiver, multiple transmitters and multiple receivers may be utilized to create a multi-static Radar unit. The number of transmitters and receivers do not have to be necessary equal.

FIG. **40**A is a line diagram depicting an exemplary 3-dimensional map generation using monostatic RADARs, in accordance with an embodiment of the invention. In this, the vehicle **3800** may be provided with multiple monostatic RADAR units **4002**. In a preferred embodiment, at least one monostatic RADAR unit may be placed on the front part, a rear part, left the side, right side, and top of the vehicle **3800**. There may also be other places like A and B pillars of the vehicle **3800** on which these monostatic RADAR units may be placed. Signals transmitted from one of these monostatic RADAR units, when reflected by bouncing off from objects may be received by rest of the other monostatic RADAR units and vice versa. Information so obtained by all the RADAR units may be combined to form a 3-dimensional mapping of the surrounding. The 3-dimensional map may be generated by a processor (not shown in the figure) communicably connected to the multiple RADAR units.

FIG. **40**B is a line diagram depicting an exemplary 3-dimensional map generation using bistatic RADARs, in accordance with an embodiment of the invention. In this embodiment, there may be a single bi-static RADAR unit **4004** placed on the vehicle **3800**. The bi-static RADAR unit may have a transmitting unit **40044** and receiver unit **40042** placed at different locations of the vehicle **3800**. For example, the transmitting unit **40044** may be placed in front of the vehicle **3800** whereas the corresponding receiving unit **40042** may be placed at the rear-end of the vehicle **3800**. This configuration may allow an increase in aperture size and provide a higher resolution of data. Data acquired using the bi-static RADAR unit may be processed to generate a 3-dimensional mapping of the surrounding. Hence, generating a clearer view of all the objects in the near vicinity of the vehicle **3800**.

In yet another embodiment there may be multiple bi-static RADAR units placed all over the vehicle with the corresponding transmitting and receiving unit placed at different locations. Transmitted signals from transmitting unit of one bi-static or multi-static RADAR unit when bounces off objects and get returned may be received by receiving units of all bi-static or multi-static RADAR units present on the vehicle **3800**. Data thus captured may be then utilized to create a high-resolution 3-dimensional mapping of the surrounding region.

FIG. **41** is a line diagram illustrating an exemplary 3-dimensional map generation using RADAR units present on different vehicles, in accordance with an embodiment of the invention. In this configuration, there may be present multiple vehicles **4102**, **4104**, and **4106** having their corresponding RADAR units **4108**, **4110**, and **4112**. Each of the RADAR units **4108**, **4110**, and **4112** may include their own corresponding processor (not shown in the figure). All these processors may be connected to each other wirelessly through cloud computing, mobile communication networks or connected car technology. As per the embodiment, the RADAR unit **4108** when transmits signals to identify object **4114**, the RADAR signals returned due to bouncing off from the object **4114**, are received not only by the RADAR unit **4108** but, by all the close vicinity RADAR units like **4110** and **4112** as well and vice versa. The processors of all the RADAR units **4108**, **4110**, and **4112** identify which all RADAR units are nearby or within a close proximity. The proximity may be defined or automatically adapted by the processor. When close proximal RADAR units are identified, each processor communicates with another processor to join and form an identification mode in which the returned RADAR signals from every object are received from every vehicle. The data received may then be combined in real time to generate a 3-dimensional mapping of the surroundings.

FIG. **42** illustrates an exemplary method **4200** flow diagram for an autonomous vehicle, in accordance with an embodiment of the present invention. The method **3900** corresponds to functional steps for implementation of an object detection system, such as the detection system **3700**. The order in which method is performed is not construed as limiting for the present invention. Further, various additional steps may be added in light of the scope of the present invention.

The method **4200** may include various steps such as (but are not limited to): at step **4202**, the method may detect a presence of one or more objects in one or more directions by a RADAR unit. Herein, the RADAR unit comprising: a transmitter for transmitting at least one radio signal to the one or more objects; and a receiver for receiving the at least one radio signal returned from the one or more objects. Further, the method may include, utilizing (step **4204**) at least one ultra-low phase-noise frequency synthesizer for refining the transmitted and the received signals of the RADAR unit, and thereby determining a phase-noise and maintaining the quality of the transmitted and the received radio signals.

Herein, the method may further include various steps such as receiving and multiplying, by the ultra-low phase-noise frequency synthesizer, the at least one output signal by a predefined factor to generate at least one final output signal of at least one final output frequency. Further, the method may generate the up converting or down converting the signal of the RADAR unit, by utilizing the ultra-low phase-noise frequency synthesizer.

The method **4200** (at step **4206**) may process the returned (received) signals that are refined (such as down converted) by the ultra-low phase-noise frequency synthesizer to determine one or more characteristics of the one or more objects (from where the RADAR signals are returned). For example, the method may determine the presence of a slow-moving target despite the very small Doppler frequency shift. Further, the method may include determining the presence of a close-range target despite the very short signal travel time. Furthermore, the method may determine a distance and a direction of each of the one or more objects. Again further, the method may determine a type of material an object is made up of, its geometric structure, orientation, surface characteristics and electrical characteristics. Additionally, the method may include a step of creating a RADAR image and/or activating one or more additional sensors for operation thereof in conjunction and synergy with the RADAR unit. The method may determine characteristics of two close objects irrespective of the size of the objects. Further, the method may differentiate between two or more types of the objects when one object is visually obscuring another object.

Based on the gathered information (such as the characteristics) corresponding to the objects, the method (at step **4208**) may enable an autonomous vehicle to adopt one or more actions based on the determined characteristics of the objects. In an embodiment, such actions may be suggested by the specialized processor to the autonomous vehicle (or components thereof).

Advantageously, the present invention emphasizes that by incorporating the ultra-low phase-noise synthesizer in an existing RADAR system, the performance of the RADAR system will be improved substantially in terms of target detection accuracy and resolution and because of this it can become the dominant sensor for the handling of autonomous cars. Herein, the Synthesizer drastically reduces the phase-noise of RADAR signals so that such RADAR sensor will be able to replace current sensor systems at very low cost and with reliability at all lighting and adverse weather conditions.

Further, the RADAR unit may utilize modulated or unmodulated waveforms to determine the electromagnetic characteristics such as, but not limited to, dielectric constants of targets with significantly better accuracy. Furthermore, for the RADAR unit (as disclosed herein this disclosure) that may utilize modulated or unmodulated waveforms, the processing speed of the main decision-making unit is significantly improved because the much lower phase-noise enables the RADAR to provide more accurate data with less data than a LiDAR sensor for example. Accordingly, the detection system (such as the detection system **3700**) may determine the type of material of a target object with high accuracy. Furthermore, the detection system may utilize one or more of: a camera, image processing and additional low-cost sensors for replacing the need for LADAR/LiDAR. Moreover, in an embodiment of the present disclosure, the RADAR unit (that may use modulated or unmodulated waveforms) may be utilized in conjunction with LiDAR, Camera, image processing used to create a 3D mapping of the surroundings. Additionally, the RADAR unit (that may use modulated or unmodulated waveforms) may be used in SAR applications or other RADAR application. Herein, when used in bistatic or multistatic scenarios the phase correlation between the separate transmitters and receivers may be kept between 10 to 1000 times better than with traditional RADAR systems. Further, the detection unit may determine probable events of objects (such as other vehicles in traffic area) through RADAR unit and by reducing the phase-noise through the phase-noise frequency synthesizer. Accordingly, the detection unit may pre-plan event based on the determination of probable events and may ensure safety on the road, especially during traffic time.

In an embodiment, the vehicle **3800** may include a detection system (such as the detection system **3700**) having a RADAR unit (such as the RADAR unit **3802**) that may utilize a non-modulated pulse to determine the presence of a slow-moving target despite the very small Doppler frequency shift. Further, the RADAR unit utilizes a non-modulated pulse to determine the presence of a close-range target despite the very short travel time of the signal. Further, in an embodiment, the RADAR unit utilizes at least one of: a modulated waveform and/or a non-modulated waveform to determine at least one of: the distance and more characteristics of a target, one or more characteristics of two close targets when both are the same size or one target is smaller than the other target. Further, the detection system determines a type of material a target is made up of.

Further, in an embodiment, the RADAR unit utilizes modulated or unmodulated waveforms wherein when used in conjunction with targets that utilize RADAR signal modulators can identify the modulation. Further, the detection system may utilize modulated or unmodulated waveforms in RADAR unit in conjunction with at least one of: Cameras, image processing and additional low-cost sensors to create a 3D mapping of the surroundings. Furthermore, a RADAR system that utilizes an ultra-low phase-noise synthesizer may be used as an imaging RADAR that can discover silhouettes and create a true 3-dimensional map of the surroundings of the vehicle including the mapping of the object that is not visible with light

FIG. **43** illustrates a flowchart depicting 3-dimensional map generation method **4300**, in accordance with an embodiment of the invention. The order in which method is performed is not construed as limiting for the present invention. Further, various additional steps may be added in light of the scope of the present invention.

Method **4300** may include various steps such as (but are not limited to); at step **4302**, the method may identify the presence of one or more RADAR units present nearby. The identification of the RADAR units may be based on a continuous ID signal being emitted by each of the RADAR units and proximity distance is within a threshold limit or automatically fixed by a processor of the RADAR unit **3700**. The method **4300** (at step **4304**) may then initiate a communication through a wireless network, with corresponding processors all of the RADAR units identified. The wireless networks may be mobile networks like 4G, 3G, CDMA, etc. or cloud network, or even connected car's network.

Further (at step **4306**), the processor may then initiate an identification mode switching that configures the nearby RADAR units to receive the signals returned after being bounced off from different objects. All such data is then collected by each of the processors of the RADAR units and then shared with each other as well through the wireless network. The data is then combined to generate a 3-dimensional mapping of the surrounding of the vehicle **3800** and also other proximal vehicles.

Further in an embodiment, the combined data may be uploaded by each of the proximal vehicles to a central database. The combined data may be geotagged by combining GPS information. This data is then stored in the central database with an exact model of the street of up to a distance of 1 cm. The central database may contain a repository of such street information and may keep updating it in real time whenever, new information from data collected may be identified. Hence, whenever, a new vehicle, that has never traversed the street is scheduled to cross the street, this information may be sent to the new vehicle for autonomous driving purposes. Hence, the new vehicle may forecast expected road situations, traffic, stop signs, traffic lights etc.

FIG. **44** illustrates a line diagram depicting RADAR signals from the RADAR system as presented in accordance with the present invention. There is an increase in RADAR resolution, in contrast to the resolution as depicted in FIG. **32**B, due to the usage of the Ultra-Low Phase-noise Frequency Synthesizer. The Ultra-Low Phase-noise Frequency Synthesizer is responsible for an improved CNR. The improvement in CNR results in improved angular resolution accuracy of the RADAR and hence, RADAR is able to identify a small object present on the road and also within a close vicinity as well.

FIG. **45** is a line diagram illustrating object identification, in accordance with an embodiment of the present invention. As opposed to the earlier identification problems, due to the increased resolution of RADAR signals, the RADAR signals are able to accurately identify the position of slow moving objects. With the improved CNR, the RADAR signals are also able to identify closely placed objects. In this, as can be seen, the RADAR signals, due to ultra-low phase caused due to the presence of the ultra-low phase-noise frequency synthesizer provides clear data and distinc-

tion between various objects whether obscured by other objects, slowly moving or having very close distance between each other.

Therefore, according to the present invention, the RADAR system, including the Ultra-Low Phase-noise Frequency Synthesizer, may be able to work even in adverse weather conditions. High accuracy is achieved using such RADAR system. High phase-noise that leads to high CNR is decreased to provide an accurate reading. Due to the decreased phase-noise, cluttered, blurred or multiple appearances of slow-moving objects or closely placed objects may be eliminated. The decreased CNR ratio also improves the angular resolution of the RADAR to identify closely present small objects. The RADAR system of the present invention may also be able to identify material composition of objects present within its vicinity. Hence, effectively distinguishing between humans and wooden poles. The Ultra-Low Phase-noise Frequency Synthesizer present within the RADAR may improve phase-noise by more than 20 dBc/Hz.

FIG. **46**A illustrates a line diagram depicting identification of obscured objects by the RADAR unit **3702**, in accordance with an embodiment of the invention. The vehicle **3800** includes the RADAR unit **3702**. The RADAR unit **3702** is able to generate RADAR signals that may identify visually obscured objects. Hence, the RADAR unit **3702**, with the help of the ultra-lowphase-noise synthesizer **3704**, may be able to identify a human **4604**, behind a tree **4602**. The ultra-lowphase-noise synthesizer **3704** helps by providing better resolution of the data. The amplitude of the transmitted and returned RADAR signals may be calculated to identify the objects that may be visually obscured. Further, electromagnetic characteristics may include permittivity, permeability, relative permeability, diamagnetism, paramagnetism among others. Electromagnetic characteristic levels of the surface of objects may be utilized to identify the type of objects in correlation with the density of the objects. In another exemplary environment, the detection system **3700**, may be able to identify a human sitting in a bus stop obscured by a poster on the bus stop. The electromagnetic characteristics principle may be utilized to identify such obscured objects.

FIG. **46**B, illustrates a method **4650** to identify visually obscured objects, in accordance with an embodiment of the invention. The method **4650** is initiated at step **4652**, wherein the detection system **3700** initiates transmission of RADAR signals to identify objects surrounding and gain knowledge of the environmental surroundings. Further at step **4654**, the returned signals that are bounced of the objects on which RADAR signals transmitted fall upon.

The method **4650** further at step **4656**, classifies the objects identified at step **4654**. Objects may be classified based on the dimensions of the objects. The object may be small, medium or large. If the object is not large the method **4650** jumps to step **4664** that will be explained later in the description. If the object identifier is classified as a large object, at step **4658**, then further at step **4660**, the method **4650** determines whether the object is a stationary object or not. such classification of objects may be performed utilizing comparison of subsequent images pixel-wise. Images may be partitioned into a multiple of pixel blocks that may be compared with pixel blocks of subsequent images in short time intervals. A difference observed may be used to classify the object as mobile and not stationary. If the object is classified as not stationary, the method **4650** jumps to step **4666** details of which will be explained later. If the object is classified as stationary, the method **4650** jumps to step **4662**.

The method **4650**, at step **4662**, focuses the RADAR signals to the object identified. This is done as the object may be a potential threat to the vehicle **3800**. This may be because there may be some obscured object behind the object determined that may pose a threat to the vehicle **3800**. Further, the method **4650** (at step **4664**) determines whether there is an obscured object behind the object and the status of the obscured objects (stationary or mobile). This may be done by a variety of method. In one method, electromagnetic characteristics of the objects may be identified by studying the returned RADAR signals. In another method, the density of the material of the objects may be utilized and matched to templates, stored, to classify the obscured objects. Also, the status of the obscured objects is identified whether they are stationary or mobile. This may be performed using the pixel-wise comparison of the returned radar signals.

At step **4666**, the method **4650**, marks the obscured object identified as a point of interest. The point of interest is an object classified to keep a track of. The priority of keeping the track of such an object is high as it may be a potential threat. Hence, the detection system **3700**, continuously monitors all such point of interest objects.

By way of example, the detection and imaging unit **3700** identifies whether there is a bus box in near vicinity or not. Further, in case there is a bus box identified, the detection and imaging unit **3700** further determines an obscured object and whether the obscured object is a potential threat or not. Like there may be an object in a poster and it might have a human figure. The RADAR **3702** is capable enough to identify whether it's a poster or a human figure. The RADAR thus may also identify what is behind the trunk of a tree. It is able to determine a deer or other animal that may cause a potential threat to the driver within the vehicle **3800**.

FIG. **47**, illustrates a line diagram depicting identification of pavement and road, in accordance with an embodiment of the invention. The vehicle **3800** while traveling the road **4702** has to identify where exactly road ends and where exactly pavement starts.

Roadway materials, especially asphalt, are heterogeneous mixtures of air, rocks, and binder. Each of the roadway materials have particular electromagnetic characteristics associated with its ability to be polarized by an electric field. The electromagnetic characteristics may be linearly related to the polarizability and may be a complex quantity. The electromagnetic characteristics may be complex having real, and imaginary components, representing energy storage and energy loss respectively to a propagating electromagnetic wave. Typically, when speaking of the dielectric constant one is referring to the real part of the electromagnetic characteristics which can be frequency dependent depending on the frequencies of interest.

The detection system **3700**, is capable of identifying clearly the blacktop road surface based on the dielectric constant of the roadway material. The density of the roadway material may be recognized with accuracy using the detection system **3700**. Due to this property, an exact image of the blacktop of the road may be recognized. It may be easy to distinguish the recognized road with dirt mud etc.

Further, it may be easy to recognize the pavement **4704**. The detection system **3700** is capable of identification of pavements as pavements are elevated at about 15 cm from the road **4702**. The detection system **3700** is capable of identifying the continued elevated pavement edge. The detection system **3700** is configured to accurately measure the elevated edge of the pavement **4704** with high-resolution signal reception.

Further the detection system **3700** is able to collect information about the surroundings for mapping purposes. Every item made out of a metal can be mapped accurately. Also, electromagnetic information about buildings, electrical poles, traffic lights, traffic sign, vegetation, below ground features and other environmental feature can be collected to create an "electromagnetic-map". Such an electromagnetic map will provide an additional layer of mapping to LiDAR and visual mapping. Electromagnetic maps will provide another layer of mapping that has not existed before and looks the same under all conditions.

In one embodiment, mapping the static metal object in the city and the specific signature of each object provide additional information on the electromagnetic-map of the city. For example, traffic lights metal poles may have different electromagnetic information and signature, that can be mapped into an electromagnetic-map of the city. In a similar way, metal, glass, concrete or wooden buildings may have different electromagnetic information and signature that can be mapped into electromagnetic-map of the city. Different buildings and objects may have different sizes, shapes, structure and build from combinations of different material. The different buildings may have different electromagnetic information and signatures that can be mapped into electromagnetic-maps. Multiple layers of these maps can be correlated to geographical maps, physical maps, visual maps, GIS maps and another type of maps.

An electronic signature of an object can be correlated to the electromagnetic-map, in a similar way that a visual image can be correlated to a "visual map" or a LiDAR-image can be correlated to a LiDAR-map. Different layers provide a different type of information for the electromagnetic information, visual information, and LiDAR information that may be synthesized into the relevant layer. Fusion of these information layers and the relevant map layers provide additional information about the objects.

Further, in another exemplary usage, the detection of human beings is possible by using the different reflection of the RADAR signals. Since the reflected signal is of high resolution from the RADAR **3702**, due to the ultra-low phase-noise therefore, it is possible to distinguish easily between various materials including humans, animals, live objects, trees, plants, concrete, glass, wall, etc. Different Radar reflections may also be achieved by utilizing different frequencies and multiple chirp and radar signal modulation types with the goal of determining the electromagnetic characteristics so that the material of and object of interest can be derived.

Further, in another exemplary usage, the detection system **3700**, may be able to identify animate and non-animate objects using the same principle of electromagnetic characteristics as discussed above. Such usage helps the detection system **3700** to identify where are humans or live objects are present on the road. Detection of humans is based on the fact that there may be some movement always due to breathing or movement of body parts (as in case of a walking person) etc. This small movement may be used to detect a human being from other objects behind a wall or bus stops. The ultra-lowphase-noise synthesizer **3704** is able to reduce the high clutter from the wall and other objects nearby to provide a clear resolution data. Furthermore, the RADAR **3702** is also able to identify and classify humans behind walls made up of different materials from a far-off distance as well.

In another embodiment of the invention, the RADAR **3702** may also be able to identify human being making a minimum of movements like waiving of their hands etc. even when they are blocked behind an opaque object. The ultra-low phase-noise synthesizer **3704** is able to reduce the clutter noise and able to do the identification. Even in conditions when the weather is adverse, like raining, snowing, darkness etc. The RADAR **3702** may detect humans from a considerable amount of distance. This may help to do away with the collision warning systems in the autonomous vehicles as they might not be required. This is so because due to very early warning times, the vehicle may be able to reroute their trajectory without being coming to a state of emergency.

Detection of human beings may be done analyzing the Fourier spectrogram of Doppler frequency. Doppler signatures for a moving object varies and the speed and distance of the movement play a role as well. also h, there might be other objects like other animals or cars due to which the Doppler signature may vary. Hence, small sections of the frequency spectrum may be analyzed individually. Since the RADAR **3702** is a high-resolution RADAR, it is capable of providing much clearer data as to slow-moving objects whether near or far with an emphasis on human beings.

Humans may also be detected using a background subtraction technique. This technique helps in detection of obscured human beings behind different kinds of object. In this technique, successive frames of the cross-correlation signals between each received signal and the transmitted signal. This technique can help in identification of moving objects, especially humans clearly in a heavily cluttered environment as well.

The RADAR **3702**, uses a micro-Doppler effect to identify humans. The micro-Doppler effect relies on low amplitude signals that make up human's Doppler Signature. These micro-Doppler signals can also be utilized to identify stationary humans by determining heartbeat from the reflected signals. Thus, in an environment full of people, due to the micro-Doppler technique and high-resolution property of the RADAR **3702**, the imaging system **3700** is able to identify, based on gait, different mobile humans and stationary humans due to the breathing patterns and the heartbeat patterns.

In addition to the above, the imaging system **3700**, using the RADAR **3702** may also be utilized to count the number of human beings after their identification. With the ultra-low noise capability of the RADAR **3702**, real-time counting of the human beings can be done. Even in highly cluttered regions, the RADAR **3702** is able to count the number of human beings efficiently.

The high-resolution power of the RADAR **3702**, as per the invention, helps the autonomous vehicle to reconstruct its surrounding environment. The reconstruction helps in gathering details just like a human being would and that too in a 3-D environment. The RADAR **3702**, may be complemented with an artificial engine that helps in beamforming and beam steering. Use of beamforming techniques helps the artificial engine to identify and classify various types of objects within the surroundings. The artificial engine may also be able to track and recognize all sorts of objects and hence further help the autonomous vehicle in its more autonomous functioning.

This high-resolution ability of the RADAR **3702** provides it superhuman like capabilities like for example seeing through the objects. Combine with a highly efficient and adaptive artificial engine, the autonomous vehicle is not only able to identify and classify objects behind large objects but also able to predict whether they object poses a threat to the autonomous vehicle or not. The pure radio signals help in clear imaging of the objects and the RADAR **3702** misses

fewer objects. The RADAR **3702**, with a highly directive RF beam, may be able to identify and accurately determine location, and speed of road objects and that too under severe weather conditions and even in disarranged environments.

In another embodiment of the invention, due to the ultra-low phase-noise property of the RADAR **3702**, it is also able to identify tiny objects as well. So, an object that may have been undetected with a RADAR having normal phase-noise skirt, may now be detected using the RADAR **3702** due to ultra-low phase-noise skirt.

Such a RADAR **3702**, when working in tandem with other sensors like LiDAR, Ultrasound, camera, and other RADAR sensors may prove to be very useful and may be able to contribute more and accurate information for the sensory fusion data. combined with accurate data from RADAR **3702**, and LiDAR, camera, and other sensor data, the imaging system **3700** may be able to provide an accurate 3-D map of the objects surrounding the vehicle.

As for the close placed object, generally due to clutter noise, the RADARs are not capable of distinguishing and classify so close placed objects. RADAR **3702**, due to the ultra-low phase-noise is able to clearly determine and classify the objects within close proximity of each other.

FIG. **48**, illustrates a block diagram of the processor **3708** of the detection system **3700** and its various internal components. The components of the processor **3708** may be hardware or software based. Further, the processor **3708** may include multiple microprocessors to perform various different functions that may be coordinated with each other to perform a coordinated output.

The processor **3708** may include a data acquisition module **4804**, a data classification module **4806**, a data comparison module **4808**, a 3-dimensional map generation module **4810**, and the identification of an object module **4812**. The processor **3708** may be configured to collect data from various other sensors like **4802**A-**4802**C (cumulatively referred to as sensors **4802**) and also from RADAR **3702**. The various other sensors may be LiDAR, camera, ultrasound sensors etc.

The data acquisition module **4804** receives data from every sensor connected to the processor **3708**. Data received is forwarded to the data classification module **4806**. The data classification module **4806** segregates what data is received from which sensor. This helps in identification of data and its source sensor. The data is then forwarded to a data comparison module **4808**. The data comparison module **4808** compares data, similar in information, from all sensors. The comparison is performed to check the data authenticity and helps in ascertaining the correctness of collected data. Further, the compared data is then forwarded to a 3-dimensional map generation module **4810**, that correlated the data from all the sensors and generates a 3-dimensional mapping of the surroundings of the vehicle **3800**. Further, the objects identification module **4812**, identifies the animate and inanimate objects utilizing continuously collecting data and comparing it with the historical data by breaking the data into pixels. Hence, the various modules working in a coordinated manner are able to produce a 3-dimensional mapping and accurately identify the stationary and mobile objects. Hence providing enough information to the vehicle **3800** to take an appropriate action during an event. In an exemplary embodiment, the sensors **4802** may be utilized to gather more information after being identified preliminarily. For e.g. the RADAR **3702** may preliminarily identify that there is a visually obscured object behind a tree etc. Then one of the sensors from the sensors **4802** like the LiDAR sensor may be focused on that specific spot identified by the RADAR **3702**. Then the LiDAR may use its high-resolution capability to identify clearly the object. Further, in another exemplary usage, the RADAR **3702** may identify that there is a live object in environment ahead of the vehicle **3800**. The imaging and detection system **3702** may then initiate the LiDAR sensor to determine more details about the live object. Hence, instead of focusing the LiDAR all around 360 degrees, it may be efficiently used as a supporting sensor and may be focused to a smaller degree of the area like 2-3 degrees and resolve objects better when preliminarily identified or determined by the RADAR **3702**. It may be understood that there might be another sensor that may also be used in place of LiDAR sensor or in conjunction with it like the camera to better understand the specifics of the object.

FIG. **49**, illustrates a flowchart of a method **4900** for identifying live objects using the detection system **3700**, in accordance with an embodiment of the invention. Live objects have the tendency to move at all times. For e.g. a human being is moving all the time. Even if the human being is stationary, it is still breathing and hence, it may be identified by capturing the chest cavity movement using appropriate frequency RADAR signals.

The method **4900**, (a step **4902**), transmits RADAR signals to identify objects surrounding and gain knowledge of the environmental surroundings. The detection system **3700** may continuously vary the frequency of transmitted signals. Various frequency signals are transmitted in order to identify and obtain more information about the objects preliminarily identified by the detection system **3700**.

Once objects are identified the method, at step **4904**, density information of the objects is obtained. The density information of the objects is determined by processing the returned RADAR signals. Further, at step **4906**, the method **4900** determines whether the object is live or not. The object, is determined to be not living, the method **4900** is terminated. However, in case the object is identified to be living, the detection system **3700**, marks the object as a point of interest object, at step **4908**. As described earlier, the point of interest is an object classified to keep a track of. The priority of keeping the track of such an object is high as it may be a potential threat. Hence, the detection system **3700**, continuously monitors all such point of interest objects.

By way of an example, the detection system **3700** identifies if there is a live object that may be obscured by some other bigger object. The vehicle **3800**, when driven in autonomous mode, needs to have information about every object within its vicinity especially the live objects like humans. Such humans may be potential threats as they may come in front of the vehicle **3800** suddenly and may cause an accident.

Advantageously, the present disclosure discloses usage of Radar with ultra-low phase-noise technology in conjunction with SAR technology or without to be combined with LiDAR as an overall surroundings mapping solution. Further, in an embodiment, the Radar with ultra-low phase-noise technology with or without SAR technology (mono-static, bi-static or multi-static) may be utilized in combination with LiDAR where the Radar provides an overall view and directs the LiDAR to points of interest. Furthermore, the Radar with ultra-low phase-noise technology in conjunction with or without SAR technology (mono-static, bi-static or multi-static) to be combined with a Camera/thermal camera to identify objects/silhouettes. Also, the Radar with ultra-low phase-noise technology in conjunction

with or without SAR technology (monostatic, bi-static or multi-static) may be utilized by combining with one or more other sensors.

Additionally, in an embodiment, the present invention discloses creating synergy between Radar and LiDAR by supporting and cross-referencing LiDAR imaging by providing information about an object surface roughness, Geometric structure, Orientation. Further, in an embodiment, SAR, InSAR, and PolSAR may be utilized to achieve the advantages. Furthermore, exchange/completion of data between vehicles—low phase-noise ensures accurate knowledge about the distance between the vehicles which is crucial for such type of information exchange/completion.

Hence, the RADAR unit **3702**, according to a present embodiment of the invention is able to identify moving human beings in severe weather conditions may be dark, snow, rain, etc. the RADAR **3702** is able to identify the humans behind stationary objects like a tree and able to identify and classify the various objects. The humans are identified from a safe distance which may eliminate the need for a collision warning system as it will not be required. The RADAR **3702** may also be able to identify materials of the objects on the road like for example bike material etc.

Examples of sensor fusion with better visual interpretation:

1. Pedestrian approaching a crosswalk:

The RADAR **3702** classifies the pedestrian based on material detection of the human living body. RADAR **3702** further classifies the pedestrian based on micro doppler of the limb movement. After detection and classification, by the RADAR **3702**, from a long range, it alerts the LiDAR and the Camera sensors to focus on the specific location and clarify the detection and classification.

Pedestrian is further classified by the LiDAR on basis of shape; and

Further, the cameras as well classify the pedestrian. All the identified information is then fed into the processing unit that forms a decision to stop for the pedestrian to cross.

2. A cyclist on the road:

The RADAR **3702** classifies the cyclist based on material detection of the human living body. The RADAR **3702** classifies the cyclist based on material detection of cycle metal from a very long range. RADAR **3702** further classifies the cyclist based on sinusoidal micro doppler of the pedal movement.

After detection and classification, by the RADAR **3702**, from a long range, it alerts the LiDAR and the Camera sensors to focus on the specific location and clarify the detection and classification.

A cyclist is further classified by the LiDAR on basis of shape; and

The cyclist, the cameras as well classifies the pedestrian.

All the identified information is then fed into the processing unit that forms a decision to increase the distance from the cyclist.

3. A deer or other animal on the side of the road:

The RADAR **3702**, due to the high resolution gained from the ultra-low phase-noise signal in the captured information has the ability to detect and determine a deer from a very long range, even in adverse weather conditions such as n fog, rain, snow or even in darkness. The RADAR **3702** is also able to detect the presence of the deer even when the deer is obscured behind another object like a tree, bushes, or a wooden wall.

FIG. **50**, illustrates a block diagram of a detection system **5000** for detecting surrounding environment, in accordance with an embodiment of the invention. The system **5000** is similar to the detection system **3700** as discussed in conjunction with FIG. **37**.

The system **5000** includes, but not limited to a first sensor or the RADAR unit **3702**, as has been described above in conjunction with FIG. **39**, the ultra-low phase-noise frequency synthesizer **3704**, a processor **5004**, at least one-second sensor **5002**, and a database **5006**.

The RADAR unit **3702** may be configured for detecting the presence of one or more objects/targets in one or more directions by transmitting radio signals in the one or more directions. In an embodiment, the RADAR unit **3702** may be comprised of at least one of or combination of: a traditional RADAR system, a synthetic aperture RADAR, or different types of RADAR with different RADAR subsystems and antennas.

The at least one-second sensor **5002** may be a LiDAR, that emits light periodically to gather data about the surroundings. The function of the LiDAR has been discussed above in detail.

The ultra-low phase-noise frequency synthesizer **3704** (hereinafter may interchangeably be referred to as 'frequency synthesizer **3704**') may be providing the needed carrier frequency, or a multiple or a fraction of the needed carrier (or up-conversion) frequency for the RADAR transmitter section. The ultra-low noise frequency synthesizer **3704** may also be providing the needed carrier (or down-conversion) frequency, or a multiple or a fraction of the needed carrier frequency for the RADAR receiver section. For some RADARs the transmit signal is used as the carrier frequency for the receive section, this does not alter the principle of this invention and is merely another form of implementation. The term "carrier" may be used interchangeably referring to an up-conversion or down-conversion signal.

The database **5006** may include instructions set having one or more specialized instructions. The specialized instructions may be executable by the processor **5004**.

In an embodiment, the RADAR unit **3702** of the system **5000** may be placed in-front of the vehicle **3800**, or anywhere else in or on the vehicle **3800**, to transmit the radio signals in various directions and further to receive the returned radio signals as returned from the object(s) (after hitting the object(s)).

Further, the specialized instruction on execution by the processor **5004** gathers information corresponding to the surroundings, the information is gathered based on the returned radio signal. The information gathered may include, but is not limited to, surrounding information of the object(s) such as road structure, traffic in front of those objects, traffic behavior, the response of the one or more objects based on the traffic behavior. Further, based on analysis of these, the system **5000** may mark the one or more objects identified as an object of interest. The object of interest may be a potential threat to the vehicle **3800**. The processor **5004** decides and performs pre-planning corresponding to probable moves that may be required in near future. Such intelligent planning of the system **5000** may determine probable events on the road. This further ensures safety on the road. Further, the information corresponding to the objects and surrounding may be stored in the database **5006** for future reference and planning. Furthermore, the information may be provided to an output device (not shown) such as a display. The information may also be transferred to a Database outside of the autonomous vehicle such as, but not limited to, a cloud-based database.

FIG. **51**, illustrates an exemplary method **5100** flow diagram for detecting and imaging objects for a vehicle, in accordance with an embodiment of the invention. The method **5100** corresponds to functional steps for implementation of an object detection system, such as the detection system **5000**. The order in which method is performed is not construed as limiting for the present invention. Further, various additional steps may be added in light of the scope of the present invention.

The method **5100** may include various steps such as mentioned below, but, not limited to the ones as described. The method **5100**, starts at step S**102** wherein the method **5102** scans the surrounding environment. Herein, the RADAR unit **3702** comprising: a transmitter for transmitting at least one radio signal to one or more objects in the surrounding; and a receiver for receiving the at least one radio signal returned from the one or more objects in the surrounding. The method **5102** may include, generating (at step S**104**) a preliminary data of the surrounding environment. The preliminary data may include various small and large, stationary and mobile object information. Preliminary data may identify preliminary details about surrounding environment for example, where exactly are the objects present at what approximate direction and distance. Further, the method **5100** determines (at step S**106**), if there is an object that may be marked as an object of interest. The object of interest may be an object that may pose a potential threat to the vehicle **3800**. This object may be an animal behind a tree, a child behind a vehicle a vehicle that has been put to ignition at the very moment of scanning, a person sitting in a bus station, etc. Further, the method **5100** initiates (at step S**108**) the at least second sensor **5002**. The at least second sensor may be, as described earlier, a LiDAR, a thermal camera, or an ultrasound sensor. Such initiation helps in targeting the more resolution power of the second sensor **5002** to be targeted selectively to such part of the surrounding environment that may present a potential threat to the vehicle **3800**. The at least second sensor **5002**, obtain (at step S**110**) supporting information about the object of interest. The supporting information may be information about size, edges, outline, actual classification of the object etc. Once the supporting information has been gathered, the method **5100** combines (at step S**112**) preliminary and supporting information about the surrounding environment. The method **5100** generates (at step S**114**) a 3-dimensional image of the surrounding image in order to provide a holistic and near natural image to the vehicle **3800**.

The first sensor **3702** that is the RADAR unit **3702** and the at least one-second sensor may obtain data using different techniques. The second sensor may be equipped to obtain or provide data with more resolution and up to a very close distance to the vehicle **3800**.

FIG. **52**, illustrates a block diagram of the processor **5004** and its various internal components to perform detection of objects, according to an embodiment of the invention. The processor **5004** includes (but not limited to) various modules as listed. The processor **5004** may include a data acquisition module **5052**, a preliminary data module **5054**, a sensor control module **5056**, a support data module **5058** and a 3-d data module **5060**.

The components of the processor **5004** may be hardware or software based. Further, the processor **5004** may include multiple microprocessors (as components) to perform different functions that may be coordinated with each other to perform a coordinated output.

The data acquisition module **5052** is configured to accept data from the first sensor **3702** and the at least one-second sensor **5002**. The data acquisition module **5052** translates the data from sensors **3702** and **5002** to a format readable to the other parts of the processor **5004**.

The sensor control module **5056** is configured to control the initiation, speed and data acquisition from the sensors **3702** and **5002**.

The preliminary data from the first sensor or the RADAR unit **3702** is received by the preliminary data module **5054**. The preliminary data module **5054** identifies if there is an object of interest that is present in the data. in a situation, an object of interest is determined, the preliminary data module **5054** forwards this information to the sensor control module **5056**. The sensor control module **5056**, initiates the at least one-second sensor **5002** to capture more data about the object of interest. By initiation, the sensor is basically activated that may be in off state before initiation or in a state wherein it may not be collecting data. However, in other embodiment of the invention, the sensor may be generally collecting information without focusing on a specific area of surrounding or a specific object. Data acquired by the at least one-second sensor **5002** is then translated in a format that may be appropriate to read by the support data module **5058**. The support data module reads and generates more information about the object of interest. Both the preliminary data and the support data is also forwarded to the 3-dimensional data module to combine the two types of data and generate a holistic picture of the surrounding including all objects, road, pavement, etc.

FIG. **53**, illustrates a method **5300** flowchart for identification of a potential threat object to the vehicle **3800** using the detection system **5000**, in accordance with an embodiment of the invention. The method **5300** may include additional or lesser steps. The steps presented here need not be considered limiting to the invention.

The method **5300**, at step S**302**, receives 2-dimensional data captured using the RADAR unit **3702**. Further, at step S**304**, the RADAR data is processed for identifying the surrounding environment information and various objects in it. Further, at step S**306**, the object of interest is identified by the method **5300**. In an embodiment, there may be multiple objects of interests identified by the RADAR unit **3702**. This information is used by the method **5300** to initiate, at step S**308**, LiDAR sensor **5002** (the at least one-second sensor is interchangeably referred to as LiDAR sensor **5002**). The LiDAR sensor **5002** obtains, at step S**310**, multiple data set pints of the object of interest. At step S**312**, the method identifies information from the multiple dataset points like edges, curves, etc. Further, at step S**314**, the 2-dimensional data and the multiple data set points are combined and at step S**316**, a 3-dimensional image of the object or objects of interest is generated.

FIG. **54**, illustrates a block diagram displaying advantages of using selective use of the at least second sensor, in accordance with an embodiment of the invention. As mentioned, the at least one second sensor **5002**. The RADAR unit **3702** may look all around the vehicle **3800** as represented by azimuth area **5402**. So, the RADAR unit **3702** will sweep the entire azimuth area. Then in a scenario that the object of interest is identified, the LiDAR **5002** may be directed to that particular area **5404**. Such selective scanning helps to reduce the computing cycle of azimuth area **5402** by approximately $1/100^{th}$ of a general scenario when LiDAR is sweeping the full azimuth itself. This happens because of the amounts of data reduced by the selective scanning use of the LiDAR **5002**.

FIG. **55**, illustrates a block diagram displaying advantages of using selective use of the at least second sensor, in

accordance with an embodiment of the invention. The RADAR **3702** may sweep an entire elevation region **5406** initially for preliminary data. In a scenario that object of interest is determined to be within the preliminary data, the LiDAR sensor **5002** is then directed to obtain more information about the same area **5408** as shown in the figure. The selective scanning helps to reduce the computing cycle of azimuth area by approximately 1/10 of a general scenario when LiDAR is sweeping the full elevation **5406** itself. This happens because of the amounts of data reduced by the selective scanning use of the LiDAR **5002**.

Combining the azimuth area computing cycle saving and the elevation area computing cycle saving, the detection system **5000**, as per the invention, is able to save 1/1000 computing cycles. Hence the amount of data to be processed is lowered by a minimum of 1/1000 of the data than from a situation when the full computation is performed by LiDAR itself.

Further, the redundant data also helps in providing a better data representation and surety of the data obtained. It may also decrease the amount of computing power required as large amounts of data generated by a full servicing LiDAR is also reduced significantly.

FIG. **56** illustrates a method **5600**, for recognition of a living body by the RADAR **3702**. The method **5600**, (a step S**602**), transmits RADAR signals to identify objects surrounding and gain knowledge of the environmental surroundings. The detection system **3700** may continuously vary the frequency of transmitted signals. Various frequency signals are transmitted in order to identify and obtain more information about the objects preliminarily identified by the detection system **3700**.

Once objects are identified by the method, at step S**604**, information about the electromagnetic characteristics of the material of the object is obtained. The information of the type of the material of the objects is determined by processing the returned RADAR signals. At step S**605**, additional Radar information of objects is obtained. This additional Radar information may include information such as Doppler, micro-Doppler, velocity, size, shape, placement among other radar information types.

Further, at step S**606**, the method **5600** determines whether the object is live or not. If the object, is determined to be not human or living body, the method **5600** is terminated. However, in case the object is identified to be living, the detection system **3700**, marks the object as a point of interest object, at step S**608**. As described earlier, the point of interest is an object classified to keep a track of. The priority of keeping the track of such an object is high as it may be a potential threat. Hence, the detection system **3700**, continuously monitors all such point of interest objects.

FIG. **57**, illustrates an exemplary method **5700** flow diagram for detecting and imaging objects for a vehicle, in accordance with an embodiment of the invention. The method **5700** corresponds to functional steps for implementation of an object detection system, such as the detection system **3700**. The order in which method is performed is not construed as limiting for the present invention. Further, various additional steps may be added in light of the scope of the present invention.

The method **5700** may include various steps such as mentioned below, but, not limited to the ones as described. The method **5700**, starts at step S**702** wherein the method **5702** scans the surrounding environment. Herein, the RADAR unit **3702** comprising: a transmitter for transmitting at least one radio signal to one or more objects in the surrounding; and a receiver for receiving the at least one radio signal returned from the one or more objects in the surrounding. The method **5702** may include, generating (at step S**704**) a preliminary data of the surrounding environment. The preliminary data may include various small and large, stationary and mobile object information. Preliminary data may identify preliminary details about surrounding environment for example, where exactly are the objects present at what approximate direction and distance. Further, the method **5700** determines (at step S**706**), if there is an object that may be marked as an object of interest. The object of interest may be an object that may pose a potential threat to the vehicle **3800**. This object may be an animal behind a tree, a child behind a vehicle a vehicle that has been put to ignition at the very moment of scanning, a person sitting in a bus station, etc. Further, the method **5700** initiates (at step S**708**) other sensors. The other sensors may be, as described earlier, a LiDAR, a thermal camera, or an ultrasound sensor. Such initiation helps in targeting the more resolution power of other sensors to be targeted selectively to such part of the surrounding environment that may present a potential threat to the vehicle **3800** and obtain more clear and redundant information about the object of interest. The other sensors, obtain (at step S**710**) supporting information about the object of interest. The supporting information may be information about size, edges, outline, actual classification of the object etc. Once the supporting information has been gathered, the method **5700** combines (at step S**712**) preliminary and supporting information about the surrounding environment. The method **5700** generates (at step S**714**) a 3-dimensional image of the surrounding image in order to provide a holistic and near natural image to the vehicle **3800**.

FIG. **58**, illustrates a block diagram of a detection system **5800** for detecting surrounding environment, in accordance with an embodiment of the invention. The system **5800** is similar to the detection system **3700** as discussed in conjunction with FIG. **37**.

The system **5800** includes, but not limited to a first sensor or the RADAR unit **3702**, as has been described above in conjunction with FIG. **39**, the ultra-low phase-noise frequency synthesizer **3704**, a processor **5804**, at least one-second sensor **5802**, and a database **5806**.

The RADAR unit **3702** may be configured for detecting the presence of one or more objects/targets in one or more directions by transmitting radio signals in the one or more directions. In an embodiment, the RADAR unit **3702** may be comprised of at least one of or combination of: a traditional RADAR system, a synthetic aperture RADAR, or different types of RADAR with different RADAR subsystems and antennas.

The at least one-second sensor **5800** may be a LiDAR, that emits light periodically to gather data about the surroundings. The function of the LiDAR has been discussed above in detail.

The ultra-low phase-noise frequency synthesizer **3704** (hereinafter may interchangeably be referred to as 'frequency synthesizer **3704**') may be providing the needed carrier frequency, or a multiple or a fraction of the needed carrier (or up-conversion) frequency for the RADAR transmitter section. The ultra-low noise frequency synthesizer **3704** may also be providing the needed carrier (or down-conversion) frequency, or a multiple or a fraction of the needed carrier frequency for the RADAR receiver section. For some RADARs the transmit signal is used as the carrier frequency for the receive section, this does not alter the principle of this invention and is merely another form of

implementation. The term "carrier" may be used interchangeably referring to an up-conversion or down-conversion signal.

The database **3706** may include instructions set having one or more specialized instructions. The specialized instructions may be executable by the processor **5004**.

In an embodiment, the RADAR unit **3702** of the system **5800** may be placed in front of the vehicle **3800**, or anywhere else in or on the vehicle **3800**, to transmit the radio signals in various directions and further to receive the returned radio signals as returned from the object(s) (after hitting the object(s)).

Further, the specialized instruction on execution by the processor **5804** gathers information corresponding to the surroundings, the information is gathered based on the returned radio signal. The information gathered may include, but is not limited to, surrounding information of the object(s) such as road structure, traffic in front of those objects, traffic behavior, the response of the one or more objects based on the traffic behavior. Further, based on analysis of these, the system **5800** may mark the one or more objects identified as an object of interest. The object of interest may be a potential threat to the vehicle **3800**. The processor **5804** decides and performs pre-planning corresponding to probable moves that may be required in near future. Such intelligent planning of the system **5800** may determine probable events on the road. This further ensures safety on the road. Further, the information corresponding to the objects and surrounding may be stored in the database **5806** for future reference and planning. Furthermore, the information may be provided to an output device (not shown) such as a display. The information may also be transferred to a Database outside of the autonomous vehicle such as, but not limited to, a cloud-based database.

FIG. **59** illustrates a block diagram of the processor **5804** and its various internal components to perform detection of objects, according to an embodiment of the invention. The processor **5804** includes (but not limited to) various modules as listed. The processor **5804** may include a data acquisition module **5952**, a preliminary data module **5954**, a sensor control module **5956**, a support data module **5958** and a 3-d data module **5960**.

The components of the processor **5804** may be hardware or software based. Further, the processor **5804** may include multiple microprocessors (as components) to perform different functions that may be coordinated with each other to perform a coordinated output.

The data acquisition module **5952** is configured to accept data from the first sensor **3702** and the at least one-second sensor **5802**. The data acquisition module **5052** translates the data from sensors **3702** and **5802** to a format readable to the other parts of the processor **5804**.

The sensor control module **5956** is configured to control the initiation, speed and data acquisition from the sensors **3702** and **5802**.

The preliminary data from the first sensor or the RADAR unit **3702** is received by the preliminary data module **5954**. The preliminary data module **5954** identifies if the identified object is a human body by comparing the electromagnetic characteristics of the surface of the human body present in the returned data. If the object identified is determined to be human, the preliminary data module **5954** marks it as an object of interest and forwards this information to the sensor control module **5956**. The sensor control module **5956**, initiates the at least one-second sensor **5802** to capture more data about the object of interest and verify the data obtained by preliminary data module **5954**. By initiation, the sensor is basically activated that may be in off state before initiation or in a state wherein it may not be collecting data. However, in other embodiment of the invention, the sensor may be generally collecting information without focusing on a specific area of surrounding or a specific object. Data acquired by the at least one-second sensor **5802** is then translated in a format that may be appropriate to read by the support data module **5958**. The support data module reads and generates more information about the object of interest. Both the preliminary data and the support data is also forwarded to the 3-dimensional data module to combine, compare and verify the presence of a human body from the two types of data.

FIG. **60** illustrates a block diagram of system **6000**, depicting formation of RADAR maps. The system **6000** includes the vehicle **3800** including RADAR **3702** is able to identify various objects while the vehicle **3800** is driving or in a mobile status. As stated above, RADAR **3702** including ultra-low phase-noise frequency synthesizer **3704**, is able to identify objects that even cameras and LiDARs may not able to recognize. The radio frequency spectrum of RADAR, LiDAR, and Camera are in different spectrums and different characteristics, and different signal range detections and resolutions. They can detect objects in different ways based on different return signals and signatures. RADAR **3702** is able to transmit radio frequency signals that collide various objects and get returned. Electromagnetic characteristics of Radio frequency of the RADAR **3702** generate a unique type of information about objects present around the vehicles. This type of information is unique to RADAR and may not visible to LiDAR and Camera.

RADAR **3702** thus identifies all stationary objects and also classifies the objects based on return signals. Since, RADAR **3702** is able to identify metal objects from a very long distance hence, it can also classify and detect type of metal object. For example, traffic light poles **6006**. They are very large, and heavy metal objects, with a specific shape and dimensions (about 10 meters high and an arm of about 10 meters in 90 degrees to the pole).

The return signal of such a traffic light structure **6006** is very strong, and clear. Millions of such Radar images and unique signatures of such traffic signals may be seen, and an Artificial Intelligence program utilizing Machine Learning may be utilized to detect unique signatures of such structures. Hence, the Radar **3702** and the Signal Processing of the Radar **3702**, may be able to detect this type of structure by classifying it as the specific traffic light structure **6006**.

Hence, when the Radar **3702** receiver detects and classifies this type of structures **6006**, it may determine exact direction and distance of this structure from the vehicle **3800**. It may measure time to transmit/receive signals and based on this may determine distance of the object. RADAR **3702** may also know exact direction/azimuth to the structure **6006**.

Now, since the exact location of each structure **6006** on the map is easily determinable, it is further easy to calculate exact location of the vehicle **3702** with respect to the structure **6006**. In this case, the distance may be measured in centimeters which may be more accurate than distance of GPS.

In the same manner other metal containing objects like buildings **6004**, pavements **6008**, road signs **6010** may also be determined and mapped within road traveled.

A new type of map can be generated ahead of time. This map includes the exact location of each of these objects and the specific radio-magnetic signature for this object. In many cases, big metal objects will have strong return signature that

can be detected from a very large distance. It is possible to navigate and know exact location of the vehicle **3800** for autonomous driving based on exact locations of various objects on the road. The exact location of the vehicle **3800** can be determined by azimuth and distance of the vehicle **3800** from each of these objects.

It is also possible to know exact location of the vehicle **3800** just based on one object. It is possible to look at many objects in different directions (including backward, forward, right and left), different distances including very long distance. Based on each one of them, it is possible to know exact location. Based on multiple objects, even better location may be determined.

Furthermore, RADAR **3702**, with the electromagnetic radio frequency may also be able to see through vegetation. That is, if a metal structure is behind trees, vegetation or a curve, the Radar **3702** still may "see" the metal structure. Drivers' eyes visualization, Cameras, and LiDAR may not be able to "see" the metal object if it is behind a tree.

Hence with RADAR **3702** including the ultra-low phase-noise frequency synthesizer **3704**, we are able to add classification to type of objects identified and determined. This may be achieved by using Artificial Intelligence, or Machine learning, Deep Learning, and Neural Networks techniques. This is because RADAR **3702** is able to add spectral clarity to objects within the road that may provide a new unique signature to metal within the objects.

After identification of the objects within vicinity of the vehicle **3800**, a RADAR map is generated that may be stored within the database **3712** of the detection system **3700**. This map may also be transmitted to a central server **6002** for further usage by other vehicles and may also be improved upon by data collected for similar area by other vehicles as well.

FIG. **61** illustrates a block diagram of a detection system **6100** for RADAR maps generation, in accordance with an embodiment of the invention. The system **6100** is similar to the detection system **3700** as discussed in conjunction with FIG. **37**.

The system **6100** includes, but not limited to at least one sensor or the RADAR unit **3702**, as has been described above in conjunction with FIG. **39**, the ultra-low phase-noise frequency synthesizer **3704**, a processor **6104**, and a database **6106**.

The RADAR unit **3702** may be configured for detecting the presence of one or more objects/targets in one or more directions by transmitting radio signals in the one or more directions. In an embodiment, the RADAR unit **3702** may be comprised of at least one of or combination of: a traditional RADAR system, a synthetic aperture RADAR, or different types of RADAR with different RADAR subsystems and antennas.

The ultra-low phase-noise frequency synthesizer **3704** (hereinafter may interchangeably be referred to as 'frequency synthesizer **3704**') may be providing the needed carrier frequency, or a multiple or a fraction of the needed carrier (or up-conversion) frequency for the RADAR transmitter section. The ultra-low noise frequency synthesizer **3704** may also be providing the needed carrier (or down-conversion) frequency, or a multiple or a fraction of the needed carrier frequency for the RADAR receiver section. For some RADARs the transmit signal is used as the carrier frequency for the receive section, this does not alter the principle of this invention and is merely another form of implementation. The term "carrier" may be used interchangeably referring to an up-conversion or down-conversion signal.

The database **6106** may include instructions set having one or more specialized instructions. The specialized instructions may be executable by the processor **6104**.

In an embodiment, the RADAR unit **3702** of the system **6100** may be placed in-front of the vehicle **3800**, or anywhere else in or on the vehicle **3800**, to transmit the radio signals in various directions and further to receive the returned radio signals as returned from the object(s) (after hitting the object(s)).

Further, the specialized instruction on execution by the processor **6104** gathers information corresponding to the surroundings, the information is gathered based on the returned radio signal. The information gathered may include, but is not limited to, surrounding information of the object(s) such as road structure, traffic in front of those objects, traffic behavior, the response of the one or more objects based on the traffic behavior. Further, based on analysis of these, the system **6100** may obtain some specific signature of each and every object within the surrounding of the vehicle **3800**. As described earlier, each and every object may have different electromagnetic information and signature. The objects identified then may be mapped relative to the vehicle **3800**. The processor **6104** calculates distance, form, and type of object and adds the information for creation of an electromagnetic map of the surroundings of the vehicle **3800**.

Further this electromagnetic map, including the unique signatures of the objects identified by the ultra-low phase-noise frequency synthesizer **3704**, may be combined together with other visual maps like LiDAR maps, physical maps etc. to provide a spectral clarity. Classification of the identified object, using the unique signatures, may be performed using various Artificial Intelligence or data science techniques.

FIG. **62** illustrates a block diagram of the processor **6104** and its various internal components to perform detection of objects, according to an embodiment of the invention. The processor **6104** includes (but not limited to) various modules as listed. The processor **6104** may include a data acquisition module **6202**, an object signature module **6204**, a sensor control module **6206**, a classification module **6208** and a map module **6210**.

The components of the processor **6104** may be hardware based. The processor **6104** may include multiple microprocessors (as components) to perform different functions that may be coordinated with each other to perform a coordinated output. The processor type can be a CPU, GPU, APU, FPGA, DSP and other types of processing power technologies. Different type of signal processing architecture and design can be implemented in preforming such computation.

In another aspect of the present subject matter, the modules may be machine-readable instructions which, when executed by a processor/processing module, perform any of the described functionalities. The machine-readable instructions may be stored on an electronic memory device, hard disk, optical disk or other machine-readable storage medium or non-transitory medium. In an implementation, the machine-readable instructions can also be downloaded to the storage medium via a network connection.

The data acquisition module **6202** may be configured to accept data from the first sensor **3702**. The data acquisition module **6202** may translate the data from the at least first sensor **3702** to a format readable to the other modules of the processor **6104**.

The sensor control module **6206** may be configured to control initiation, speed and data acquisition from the at least first sensor **3702**.

The surrounding environment data from the at least first sensor or the RADAR unit **3702** is received by the data acquisition module **6202** and forwarded to the object signature module **6204**. Object signature module **6204** obtains unique signatures of different objects from the data received. Further, the classification module **6206** classifies the objects identified using unique signatures. The classification may be based on various AI and data science techniques.

The map module **6210**, correlates all objects identified and classified and generates an electro-magnetic map for the objects within the surrounding information. Further, the map module may store these maps and various similar maps of other surroundings within a memory. The maps of various surroundings may be further combined to create a master map.

In an embodiment, electromagnetic maps of various surroundings may also be combined together, by the map module **6210**, with physical maps, visual maps, or LiDAR maps to provide more granular information to the vehicle **3800** for better maneuverability while in autonomous mode.

In another embodiment, the master map may be updated real time and continuously by information gathered from different other vehicles within various surrounding. The master map may be stored in a central location that may be connected to multiple vehicles. The master map may be combined with physical maps and information may be updated and distributed instantaneously to keep autonomous drive mode safe and up to date.

Since the mapping system **6100** utilizes specific signatures for map creation therefore, the GPS coordinates may not be required to ascertain the correct positioning of the vehicle **3800**. As, system **6100** is configured to identify the buildings and whole surrounding environment, by template matching technique, therefore the system **6100** works efficiently in areas where there is no GPS reception as well. System **6100** may utilize information from many other sensors like odometers etc. to determine exact speed and direction of the vehicle based on which accurate positioning data is predicted that helps in accurate maneuvering.

Referring to FIG. **63**, a flow chart illustrating a method **6300** for RADAR map generation, in accordance with an embodiment of the invention. The method at step **6302** initiates RADAR transmission from the RADAR unit **3702**. At step **6304**, returned RADAR signals, after collision with nearby objects are received and are further analyzed. At step **6306**, the received RADAR signals are utilized to obtain electromagnetic information about objects and near-by surroundings. At step **6308**, the electromagnetic information is further processed to obtain unique signatures of objects present in the surrounding environment. Based on the unique signatures, at step **6310**, each and every object is classified using various AI and data science techniques.

Further, at step **6312**, the unique signatures of the objects are utilized to further generate an electromagnetic map of the surrounding environment. At step **6314**, the generated electromagnetic map is combined with a physical map that is displayed to the user at step **6316**.

FIG. **64** illustrates an example embodiment of a collective mapping system **6400** that can be used to build a collective map of the surrounding environment around the vehicle **3800**. Collective mapping system **6400** includes multiple primary data sensors **6402**, multiple secondary data sensors **6404**, a processor **6406** and a memory **6408**. In the illustrated embodiments, primary data sensors include the RADAR **3702**, a LiDAR system **64022** and a vision system **64024**. RADAR **3702**, LiDAR **64022** and Vision system **64024** each are responsible to generate respectively a radar map data, LiDAR map data and image map data mapping data for use by processor **6406**.

In an embodiment of the invention, the collective mapping system **6400** may also include a plurality of secondary data sensors **6404**. The plurality of secondary data sensors **6404** are provided for real time sensing of position, location, and movement of the vehicle **3800**. The secondary data sensors **6404** may include Global position system (GPS) **64042** to provide local position of the vehicle **3800**, gyroscope sensors **64044** to calculate yaw of the vehicle **3800**, pitch and roll, speed sensor **64046**, and accelerometer **64048**. Weather conditions sensors **138** such as temperature, humidity and barometric pressure sensors may also be included with platform sensors **117**. The secondary data sensors **6404** may supplement the primary data sensors **6402** for collecting mapping data and localization of the vehicle **3800** within the map data acquired.

FIG. **65**A, illustrates a block diagram of the processor **6406** and its internal processing modules according to an embodiment of the invention. The processor **6406** may be a single unit or made of multiple processing units functioning together to achieve a common objective. In an embodiment of the invention, the multiple processing units may be hardware components. However, in another embodiment, the multiple processing units may be software modules that may be stored as instructions stored within the memory **6408**.

The processor **6406** may include multiple modules including data fetch module **64062**, data tagging module **64064**, and combination module **64066**. Operatively, data fetch module **64062** is communicably connected to the plurality of primary **6402** and secondary data sensors **6404**. Further, the data fetch module **64062** may also be connected to the memory **6408** or any other data source of a physical maps. Hence, data fetch module **64062** is configured to receive RADAR map information, LiDAR map information, Visual information and physical maps information. Further, the data fetch module **64062** may be further configured to receive the maps information simultaneously from different sources.

The data fetch module **64062** is also communicably connected to the data tagging module **64066**. The data tagging module **64064** receives data received and converted into a suitable readable format by the data fetch module **64062**. That data tagging module **64064** is configured to further tag various data and attach an identification information to each of the data. Furthermore, the data tagging module **64064** is communicable connected to a combination module **64066**. The combination module **64066** is configured to combine the different maps data received details of which will be explained in detail below.

FIG. **65**B, illustrates a block diagram of the processor **6406** and its internal processing modules according to another embodiment of the invention. The processor **6406** may include all the above-mentioned modules along with a dynamic object removal module **6408** that may be configured to remove dynamic objects from the maps data received from the plurality of primary sensors **6402**.

Dynamic objects are objects that are in continuous movement within the environment and remain in the environment for only a very small-time frame like a moving object like a human being or any animal or any other moving vehicle. Such objects may be detected by, among other things, comparing pixel details of map data from successive time slots to determine moving objects. After such identification

data of such moving objects is removed from the map data or may be highlighted within the data as being a dynamic object.

In other embodiments, as mentioned above, the RADAR **3702**, as depicted in FIG. **39** uses the transmitter **37026** that controls emitted radio signals in order to scan the surrounding environment of the vehicle **3800** for example and uses the receiver **37030** to receive the reflections from the environment around the vehicle **3800**. The RADAR **3702** is configured scan environment around the vehicle **3702** in various directions, along azimuth angles at one or more fixed elevation angles, or in a vertical plane at one or more fixed azimuth angles. The RADAR data can be processed to generate, for example, a two or three-dimensional point cloud of the environment or a radar image of the environment, which can be stored to memory **6408**. Hence with RADAR **3702** including the ultra-low phase-noise frequency synthesizer **3704**, it is possible to add classification to type of objects identified and determined. This may be achieved by using Artificial Intelligence, or Machine learning, Deep Learning, and Neural Networks techniques. This is because RADAR **3702** is able to add spectral clarity to objects within the road that may provide a new unique signature to objects. This information may also be utilized by the dynamic object removal module **64068** to further remove dynamic objects as they may be classified by the RADAR **3702** using the ultra-low phase-noise frequency synthesizer **3704**.

Further, LIDAR system **64022** is configured to scan the azimuth and elevation. Generally, a LiDAR includes dual oscillating plane mirrors, polygon mirrors, a and a laser scanner. The LIDAR system **64022** utilizes a beam splitter to collect a return signal.

Furthermore, the vision system module **64024** is configured to capture images of an environment using a charge coupled device (CCD) sensor or a Complementary Metal Oxide Semiconductor (CMOS) sensor. These sensors may be integrated in a digital camera, thermal imaging camera, night vision camera, or any other vision systems known in the art. The vision system may also include color image sensors, a multispectral imaging camera, illuminators, or any combination known in the art.

Data obtained from RADAR, LiDAR and cameras may be supplemented with data from the plurality of secondary sensors **6404**. The supplementary data may include various information like location data, positional data, movement data etc.

FIG. **66**, a flow chart illustrates a method **6600** performed by the system **6400** for creating collective map data. At step **6602**, an existing physical map for the location in which the vehicle **3800** is currently in, identified by the GPS sensor **64042** is accessed to form the base of the map information. Such physical maps may be preexisting from previously mapped information or maps uploaded by other similar system using vehicles. At step **6604**, image map information is obtained using camera sensors. Further at steps **6606** and **6608** LiDAR map information and RADAR data are simultaneously captured. In other embodiments, the steps **6602**, **6604**, **6606**, and **6608** may be carried out simultaneously.

Further at step **6610**, based on the RADAR data objects are identified and classified into various categories like stationary or dynamic objects, buildings or road signs or traffic lights etc. At step **6612**, the dynamic objects are removed or at least highlighted within the map information. In an embodiment of the invention, the RADAR map data, LIDAR map data and vision data are compared to resolve mismatch and improve the correctness for removal of dynamic objects. In situations of data mismatch, in one embodiment, dynamic object removal module **64068** compares the data for a detected dynamic object in one map data (for example the LiDAR map data) with the corresponding location data in the other map data (like RADAR and visual map information) to confirm that all three maps data conform, following which the dynamic objects are eliminated or highlighted in all three datasets.

Furthermore, on removal or highlighting of the dynamic object data from the three maps data, the data is then combined to create a map of the environment by the combination module **64066**. The combined map data will include objects identified as buildings, traffic lights, lamp posts, fire hydrants etc. Each of the objects identified based on their specific signatures and depicted within the map provided to the vehicle **3800**.

FIG. **67**A, a block diagram of a surrounding environment **6700** is depicted along with various objects within the surrounding environment, in accordance with an embodiment of the invention. The surrounding environment **6700** is mapped by obtaining and recording information from the plurality of vehicles **6702**A-D (collectively referred to as **6702**. The information is stored within a central database **6720**. In general, to generate the database **6720** the vehicles **6702** travelling along one or more lanes of the environment **6700** or other surfaces collect data regarding the roadway and nearby objects like buildings of various types **6704**, **6706**, **6708**, **6710**, **6712**, **6714**, traffic signals of different types like **6716**A, **6716**B, and various fire hydrants **6718**A-C and other objects that are not depicted here for sake of brevity. The objects can include infrastructure-based stationary targets, such as poles, streetlights, vertical guardrail posts.

The vehicles **6702** may use RADAR sensor **3702** attached to the vehicles. In addition to this there may be other sensors utilized like visual sensors or LiDAR sensors. The term roadway includes conventional public roads as well as any other area where vehicles travel such as private roads and driveways, parking lots, parking garages, tunnels, bridges, unpaved access roads, etc. Data from the various sensors is collected and stored, along with an indicator of time that the data was collected so that data from various sensors may be correlated. For example, the location of the vehicle **6702**A at the time its corresponding radar sensor reading was collected can be determined by referencing the GPS unit of the vehicle **6702**A at that same time. Similarly, data from other sensor systems can be correlated with corresponding radar sensor readings as well as the location of the vehicle **6702** obtained from the corresponding GPS units. There is no explicit assumption required on the type of objects in the object data collected, i.e. the database may not include any classification of the object. This is taken care of by the object's specific signature from the real-time data collected by RADAR **3702** and its signature stored in the database **6720**.

Further, according to an embodiment, the database **6720** may be regularly updated by incorporating data obtained from numerous vehicles traveling the various roadways equipped with RADAR units similar to RADAR **3702** and GPS or LiDAR systems. The RADAR data collected, stored locally along with accompanying GPS data, or may be transmitted from the vehicles (e.g., in real-time using wireless data communications) to the central database **6702** where it is added into the database **100**. Though, measurements from a single vehicle may be relatively inaccurate, the average of such multiple measurements provide high detailed information. Hence, data collected by traveling the

particular routes is utilize to either generate the database **6702** and also utilized to keep the database **6702** up to date, regardless of how it is initially generated.

FIG. **67**B, a block diagram illustrates localization of the vehicle **3800** while traversing the environment **6700**. The vehicle **3800** uses stored map data in the database **6720** to estimate location of the vehicle **3800** using RADAR unit that is associated with the vehicle **3800**. The vehicle **3800** collects data from the corresponding RADAR sensor, although additional data may be obtained from one or more of the other sensor systems like GPS unit, LiDAR sensor, camera sensor etc. The data obtained by the vehicle **3800** is matched up with comparable data samples from the database **6702** (FIG. **1**B).

According to an embodiment of the invention, the data from the database **6720** is saved and/or converted into a format that matches the data output of the sensors. In this embodiment the system generates a set of data that is put into a format similar to the format of the raw output of a radar sensor (or other sensors) in order to match it with the data extracted from the database **6720**.

In some embodiments, the entire database **6720** may be stored onboard the vehicle **3800** whereas in other embodiments some parts of the database **6720** may be stored onboard while the remaining portion is stored at a remote location and loaded onto the vehicle's onboard system as and when required or called for. When the vehicle **3800** travels, particularly closer to the limits of the presently-loaded portion of the database **100**, other portions of the database **6720** covering nearby regions may be loaded to provide coverage for areas in which the vehicle **3800** may travel to subsequently. Detailed information regarding the velocity and direction of the vehicle **3800** may be used to anticipate where the vehicle **3800** is going to and when it may require an access to other portions of the database **6720**.

In a general example, the RADAR **3702** combined with the ultra-low phase-noise synthesizer **3704** fitted on the vehicle **3800** sweeps the area and gathers information about the area through which the vehicle **3800** passes. The information may be gathered using chirp function of the RADAR **3702**. The chirp function along with the ultra-low phase-noise synthesizer **3704** helps to generate pseudo visual image of objects through electromagnetic waves of RADAR **3702**. This chirp function and the ultra-low phase-noise synthesizer **3704** obtain specific signatures of objects surrounding the vehicle **3800**. Each and every object generates its own specific signature. Hence it provides the way to identify and match the type of object with a database of such objects present within the environment. Dynamic objects like vehicles, humans, animals etc. can be removed from the information gathered using simply comparison methods.

Hence, with an updated database **6720**, it is possible to safely maneuver the vehicle **3800** within an environment like **6700**. Since, the RADAR signals gather high resolution information and it may be matched with already available database. By knowing the movement details like direction, speed etc. of the vehicle **3800**, it is easy to predict and know the exact current position of the vehicle. Also, it is possible to predict accurately the future position of the vehicle **3800**, to even very short intervals. Hence, if a vehicle is moving in a certain direction and gathering information of nearby objects, that are being simultaneously matched to existing data of objects, if there is any anomaly of the location it can be corrected and updated in real time. For example, in a case a vehicle is travelling a road in which a building is about to start in 10 mins, based on the current position that is based on speed of the vehicle, is noted to have been started a few minutes of the expected building location of the vehicle is updated real time. Also, such an information is useful at places wherein no GPS is available. Hence, the electromagnetic maps or RADAR maps generated by the RADAR **3702** may also function as GPS at places where GPS reception is not available.

The information gathered by the RADAR **3702** for mapping information is a pseudo visual information. This means that is equivalent of a visual image. This is possible due to high resolution data capturing of the RADAR **3702**. The electromagnetic waves transmitted from the transmitter **37026** are varied to perform chirp function that allows the obtaining of specific signatures of the objects. Basically, electromagnetic waves are utilized to calculate and generate a mathematical model equivalent of each object within the surrounding and matched with the database of such mathematical models, of various objects. Hence, after a match, the processor **6406** would know that there is a building or a traffic signal. Further, since the database already knows the location of the vehicle, hence allowing handling of the vehicle **3800** is possible within the environment.

FIG. **68**, illustrates a flow chart depicting a method **6800** for generation of navigational maps, in accordance with an embodiment of the invention. The RADAR **3702** is initiated at step **6802** to start transmitting RADAR signals. Further, at step **6804**, using other sensors within the vehicle, like odometer etc. speed and orientation of the vehicle **3800** is continuously monitored. Simultaneously, at step **6806**, point cloud data for the surroundings of the vehicle **3800** is obtained.

Further, at step **6808**, specific signatures of the objects within the surrounding environment. The specific signatures of the objects help the system **6100** to identify the type of objects. The objects are classified into stationary or dynamic objects. At step **6810**, the dynamic objects are removed from the data set obtained at previous step.

At step **6812**, the RADAR data may be supplemented with a visual data that may be either data captured using camera sensors or LiDAR sensors. Utilizing this visual data, the point cloud data, that identifies extent, size etc. of stationary objects is further utilized to generate a point cloud visualization data.

FIG. **69** depicts one example of many possible FMWC waveforms. Line **6902**A represents the transmit signal as its frequency increases, and Line **6904**B represents the transmit signal as its frequency decreases. Line **6902**B and **6904**B show the corresponding receive signals that are echoed back to the Radar receiver from an object. phase-noise. The double-sided arrows **6910** and **6912** represent the frequency difference between the transmitted and received signal, which defines the distance of that object. This frequency difference is also called f_{beat}. FIG. **69** shows a simplistic graphic representation of calculating the distance of an object with any FMCW signal without the presence of phase-noise. This results in a very deterministic frequency difference **6910** and **6912**.

FIG. **70** depicts another example of many possible FMWC waveforms, but in this instance with phase-noise. Line **7002**A represents the transmit signal as its frequency increases, and Line **7004**B represents the transmit signal as its frequency decreases.

Line **7002**B and **7004**B show the corresponding receive signals that are echoed back to the Radar receiver from an object. The double-sided arrows **7010** and **7012** again represent the frequency difference between the transmitted and received signal, which defines the distance of that object. This is the frequency difference that is also called f_{beat}. FIG.

70 shows that in the presence of Phase Noise the frequency f_{beat} is much more ambiguous and it is harder to obtain a clear measurement of this frequency and thus it is also impossible to achieve a deterministic value for the distance of the echoing object.

In an embodiment of this invention an ultra-low phase-noise synthesizer may be used to achieve a more f_{beat} and with it a more accurate distance and range measurement for one more echoing objects.

FIG. **71** depicts a common scenario where ghost objects are created as an artifact of the Radar system and the echoing from multiple objects. The real objects are described as the graph crossing in circles **7106** and **7108**. The ghost objects are described in the graph crossings in squares **7106**A and **7108**A.

The scenario of ghost objects is commonly mitigated by changing the slope or the entire shape of the FMCW chirp and then comparing 2 or more FMCW shapes to determine the location of the real object.

FIG. **72** depicts the same common scenario where ghost objects are created as an artifact of the Radar system and the echoing from multiple objects in the presence of phase-noise. The real objects are described as the graph crossing in circles **7206** and **7208**. The ghost objects are described in the graph crossings in squares **7206**A and **7208**A.

In the presence of phase-noise, and since phase-noise is a statistical phenomenon, the real objects and the ghost objects do not appear at one specific graph crossing, but rather in an area that is shown in the graph as **7206**, **7208**, **7206**A and **7208**A. This area may be created by overlaying multiple chirps.

In an embodiment of this invention the ultra-low phase-noise synthesizer may be used to determine the location of real objects faster, simpler and more accurately.

FIG. **73** shows the transformation of the frequency difference between a transmitted and received signal with the help of the Fast Fourier Transform (FFT). For simplicity only 7306 is transferred to look as **7322**. The single frequency **7322** is uniquely relative to a specific range of the echoing object. In many cases the beat frequency f_{beat} is measured multiple times during the chirp, however, in the absence of phase-noise this beat frequency will be exactly the same for every measurement resulting in a deterministic frequency representation **7322** that then can be easily calculated into range.

FIG. **74** shows the same scenario as FIG. **73** but in the presence of phase-noise. When phase-noise is present, multiple measurements of f_{beat} **7406** along the chirp will create an FFT representation of many different f_{beat} frequencies that are clustered together as shown in **7422**. When translating this into distance, a range possible distances of the echoing object will be obtained which is a disadvantage in terms of the accuracy of the entire Radar system.

In an embodiment of this invention the ultra-low phase-noise synthesizer will cause the cluster **7422** to be very narrow so that it resembles **7322**.

In another embodiment (FIG. **75**) the invention of an ultra-low phase-noise synthesizer may be used to detect stationary objects by adding phase-noise for a part of the time and then use the improved phase-noise option for another part of the time. This method will provide additional information that supports the detection of stationary object vs. moving objects.

At step **7502** a signal with bad phase-noise will be transmitted and the inaccuracy of the object location (jittering of the object over multiple parameters) will be registered in step **7504**. One of these parameters may be the doppler frequency of the object. In step **7506** a signal with ultra-low phase-noise will be transmitted and in step **7508** the data from this transmission will be collected. Step **7510** compares the data obtained from steps **7502** and **7506**. In the case where the doppler frequency is 0 Hz or sufficiently close to 0 Hz and no jittering of the object could be registered for the 2nd transmit, the echoing object is stationary and the decision-making process of a vehicle, for example, could decide to stop the vehicle or start an avoidance maneuver sequence.

FIG. **76** shows a common analysis of Radar signals on 2 dimensional FFT grid. One dimension is the Range (or distance) of the echoing object and the other is the velocity of the echoing object. The darker unit square the more energy is echoed back from that spot.

With traditional Radars an object at a certain range with a certain velocity manifests itself with very high energy in a few neighboring unit squares as can be seen at **7602**A and **7604**A. Since the energy is spread over several unit squares, it is very difficult for a decision-making system to determine the distance end velocity of an object. In addition, many modern Radar systems use multiple transmit and receive paths mainly to determine the direction of arrival of the echoing signal which multiplies the complexity of the 2-dimensional FFT grid.

In an embodiment of this invention a Radar system utilizing an ultra-low phase-noise synthesizer will create much smaller areas of energy on the 2-dimensional FFT grid because the energy of the echoed back from and object will be much more focused and with a higher amplitude at in that area.

7602B and **7604**B show the echo of the same targeted objects as in **7602**A and **7602** as it would be created by a Radar System utilizing an ultra-low phase-noise synthesizer. The energy is concentrated in fewer grid squares which means that the location and velocity of the object can be determined much more accurately. Relating this principal to Multiple Input Multiple Output (MIMO) Radar Systems for each transmit and receive path pair such a matrix may be created. A multiple array of 2-dimensional FFT matrices may be used to determine the angle of arrival of multiple echoing signals returning from the same object. Since the matrices created by a Radar system utilizing an ultra-low phase-noise synthesizer is very accurate in terms of determining the distance and velocity of the object this set of matrices may be used to determine the angle of arrival of these echoes accurately and this determine the exact location and velocity of the object.

The methods above are in addition to the improved clutter to Signal or Signal to Interference and Noise ratio (SINR).

FIG. **77** illustrates an example embodiment of a long range, ample time advanced notice detection and classification system. The system provides data about the potential and probability of the existence of an object at a long-range distance. This data may be fused with other sensors for early processing and focusing to the area and direction of the suspected object. The system **7700** may be used as a long-range detection system of the surrounding environment around the vehicle **3800**. The long-range radar detection system **7700** includes multiple primary data sensors **7702**, multiple secondary data sensors **7704**, a processor **7706** and a memory **7708**. In the illustrated embodiments, primary data sensors include the RADAR **3702**, a LiDAR system **77022** and a vision system **77024**.

RADAR **3702** is responsible to provide long-range early detection data. LiDAR **77022**, Vision system **77024**, Sensor **7704**, Processor **7706** and Memory **7708** are responsible for

processing the long-range early detection data. The processor **7706** may poll different sensors to gather more data as part of the detection and classification process needed for perception. The polling mechanism may rely on processing **7706** or memory **7708** or both. The polling by processor **7706** may also instruct sensors **7702** and **7704** to focus on specific areas at which an object was detected by RADAR **3702**.

Processor **7706** and Memory **7708** may be on a central computation system in the autonomous vehicle or outside of it. The processor **7706** and Memory **7708** may also be embedded as part of the sensor set **7702** or **7704** to allow a direct closed loop computation among multiple sensors and allow long-range early detection. The processing power of **7702** and **7704** may exist in one of the sensors or distributed among them.

The processor **7706** and Memory **7708** may also take a form of distributed processing relying on processing power available in sensors, low utilized processors in the vehicle and outside of it.

While the invention has been described in detail, modifications within the spirit and scope of the invention will be readily apparent to those of skill in the art. Such modifications are also to be considered as part of the present disclosure. In view of the foregoing discussion, relevant knowledge in the art and references or information discussed above in connection with the Background, which are all incorporated herein by reference, further description is deemed unnecessary. In addition, it should be understood that aspects of the invention and portions of various embodiments may be combined or interchanged either in whole or in part. Furthermore, those of ordinary skill in the art will appreciate that the foregoing description is by way of example only and is not intended to limit the invention.

The foregoing discussion of the present disclosure has been presented for purposes of illustration and description. It is not intended to limit the present disclosure to the form or forms disclosed herein. In the foregoing Detailed Description, for example, various features of the present disclosure are grouped together in one or more embodiments, configurations, or aspects for the purpose of streamlining the disclosure. The features of the embodiments, configurations, or aspects may be combined in alternate embodiments, configurations, or aspects other than those discussed above. This method of disclosure is not to be interpreted as reflecting an intention the present disclosure requires more features than are expressly recited in each claim. Rather, as the following claims reflect, inventive aspects lie in less than all features of a single foregoing disclosed embodiment, configuration, or aspect. Thus, the following claims are hereby incorporated into this Detailed Description, with each claim standing on its own as a separate embodiment of the present disclosure.

Moreover, though the description of the present disclosure has included description of one or more embodiments, configurations, or aspects and certain variations and modifications, other variations, combinations, and modifications are within the scope of the present disclosure, e.g., as may be within the skill and knowledge of those in the art, after understanding the present disclosure. It is intended to obtain rights which include alternative embodiments, configurations, or aspects to the extent permitted, including alternate, interchangeable and/or equivalent structures, functions, ranges or steps to those claimed, whether or not such alternate, interchangeable and/or equivalent structures, functions, ranges or steps are disclosed herein, and without intending to publicly dedicate a patentable subject matter.

We claim:

1. A system for detecting the surrounding environment of a vehicle comprising:

at least first sensor, configured to obtain data, the at least first sensor comprising:

A) a transmitter for transmitting at least one radio signal to the one or more objects within the surrounding environment;

B) a receiver for receiving the at least one radio signal returned from the one or more objects; and

C) at least one ultra-low phase noise frequency synthesizer configured to determine phase noise and quality of the transmitted and the received at least one radio signal, wherein the at least one ultra-low phase noise frequency synthesizer comprises at least one sampling Phase Locked Loop (PLL) and at least one main PLL, said Sampling PLL comprises a sampling phase detector and said main PLL comprises a high frequency digital phase/frequency detector; and

a processing unit coupled to the at least first sensor configured to;

a) gather, electro-magnetic information about the one or more objects;

b) classify or recognize each of the one or more objects by analyzing the data, wherein the classification or recognition is based on a unique signature obtained from each of the one or more objects;

c) generate an electromagnetic map of the surrounding environment by utilizing unique signatures of the one or more objects; and

d) combine the electromagnetic map with a geographical map or physical map.

2. The system of claim **1**, wherein the at least first sensor is a RADAR sensor.

3. The system of claim **1**, wherein the data includes information about the electromagnetic properties and characteristics about the object of interest or the surroundings of the vehicle.

4. The system of claim **1**, wherein the data includes shape, silhouette, doppler or micro doppler information.

5. The system of claim **1**, wherein the data includes depth, dimensions, direction, height, distance and placement of the object of interest with respect to the vehicle.

6. The system of claim **1**, wherein the classification type of the one or more objects includes living or non-living thing, stationary or moving object, animal or human, standing or mobile human, metal, wood, or concrete.

7. A system for detecting the surrounding environment of a vehicle comprising:

at least first sensor, configured to obtain data, the at least first sensor comprising;

A) a transmitter for transmitting at least one radio signal to the one or more objects within the surrounding environment;

B) a receiver for receiving the at least one radio signal returned from the one or more objects; and

C) at least one ultra-low phase noise frequency synthesizer configured to determine phase noise and quality of the transmitted and the received at least one radio signal, wherein the at least one ultra-low phase noise frequency synthesizer comprises at least one sampling Phase Locked Loop (PLL) and at least one main PLL, said Sampling PLL comprises a

sampling phase detector and said main PLL comprises a high frequency digital phase/frequency detector; and

a processing unit coupled to the at least first sensor configured to;

a) gather, electro-magnetic information about the one or more objects;

b) classify or recognize each of the one or more objects by analyzing the data, wherein the classification or recognition is based on a unique signature obtained from each of the one or more objects;

c) generate an electromagnetic map of the surrounding environment by utilizing unique signatures of the one or more objects; and

d) combine the electromagnetic map with a geographical map or physical map.

8. The system of claim **7**, wherein the sensor is a RADAR sensor.

9. The system of claim **7**, wherein the data includes information about the electromagnetic properties and characteristics about the object of interest or the surroundings of the vehicle.

10. The system of claim **7**, wherein the data includes shape, silhouette, doppler or micro doppler information.

11. The system of claim **7**, wherein the data includes depth, dimensions, direction, height, distance and placement of the object of interest with respect to the vehicle.

12. The system of claim **7**, wherein the classification type of the object of interest includes living or non-living thing, stationary or moving object, animal or human, standing or mobile human, metal or wood.

13. A system for detecting the surrounding environment of a vehicle comprising:

at least first sensor, configured to obtain data, the at least first sensor comprising

A) a transmitter for transmitting at least one radio signal to the one or more objects within the surrounding environment;

B) a receiver for receiving the at least one radio signal returned from the one or more objects; and

C) at least one ultra-low phase noise frequency synthesizer configured to determine phase noise and quality of the transmitted and the received at least one radio signal, wherein the at least one ultra-low phase noise frequency synthesizer comprises at least one sampling Phase Locked Loop (PLL) and at least one main PLL, said Sampling PLL comprises a sampling phase detector and said main PLL comprises a high frequency digital phase/frequency detector; and

a processing unit coupled to the at least first sensor configured to;

a) gather, electro-magnetic information about the one or more objects;

b) classify or recognize each of the one or more objects by analyzing the data, wherein the classification or recognition is based on a unique signature obtained from each of the one or more objects;

c) generate an electromagnetic map of the surrounding environment by utilizing unique signatures of the one or more objects; and

d) combine the electromagnetic map with a geographical map or physical map.

14. The system of claim **13**, wherein the sensor is a RADAR sensor.

15. The system of claim **13**, wherein the data includes information about the electromagnetic properties and characteristics about the object of interest or the surroundings of the vehicle.

16. The system of claim **13**, wherein the data includes shape, silhouette, doppler or micro doppler information.

17. The system of claim **13**, wherein the data includes depth, dimensions, direction, height, distance and placement of the object of interest with respect to the vehicle.

18. The system of claim **13**, wherein the classification type of the object of interest includes living or non-living thing, stationary or moving object, animal or human, standing or mobile human, metal, wood, or concrete.

19. A method for detecting the surrounding environment of a vehicle comprising:

A. utilizing at least a first sensor to obtain a data, the at least first sensor being utilized for:

i. transmitting, by a transmitter, at least one radio signal to the one or more objects within the surrounding environment;

ii. receiving, by a receiver, the at least one radio signal returned from the one or more objects; and

iii. determining phase noise and quality of the transmitted and the received at least one radio signal by at least one ultra-low phase noise frequency synthesizer, wherein the at least one ultra-low phase noise frequency synthesizer comprises at least one sampling Phase Locked Loop (PLL) and at least one main PLL, said Sampling PLL comprises a sampling phase detector and said main PLL comprises a high frequency digital phase/frequency detector; and

B. gathering, electro-magnetic information about the one or more objects;

C. classifying or recognize each of the one or more objects by analyzing the data, wherein the classification or recognition is based on a unique signature obtained from each of the one or more objects;

D. generating an electromagnetic map of the surrounding environment by utilizing unique signatures of the one or more objects; and

E. combining the electromagnetic map with a geographical map or physical map.

20. The method of claim **19**, further comprising recognizing the object on interest after classifying, wherein the classification of the object of interest includes living or non-living thing, stationary or moving object, animal or human, standing or mobile human, metallic, wooden, or concrete objects.

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