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Nickel

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(54) **NAVIGATION INFRASTRUCTURE FOR MOTOR VEHICLES**

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(51) **Int. Cl.**

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G05D 1/02	(2020.01)
H01Q 1/32	(2006.01)
G06K 7/10	(2006.01)

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CPC ***B62D 15/0255*** (2013.01); ***G01C 21/26*** (2013.01); ***G05D 1/0259*** (2013.01); ***G06K 7/10366*** (2013.01); ***H01Q 1/32*** (2013.01)

(58) **Field of Classification Search**
USPC 701/41
See application file for complete search history.

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(74) *Attorney, Agent, or Firm* — Hugh P. Gortler

(57) **ABSTRACT**

A transit system includes a road, a plurality of pavement markers spaced apart along a lane line of the road, and a plurality of RF devices carried by the pavement markers. The RF devices are configured to transmit RF navigation signals to motor vehicles traveling along the road.

26 Claims, 7 Drawing Sheets

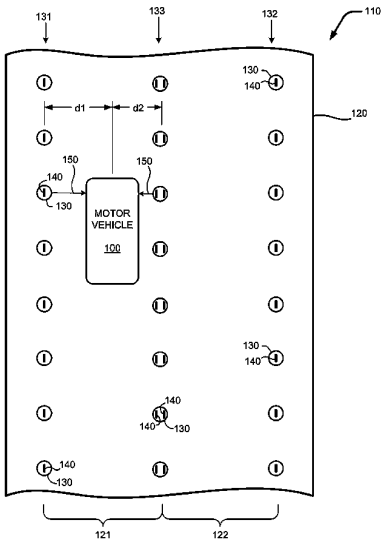

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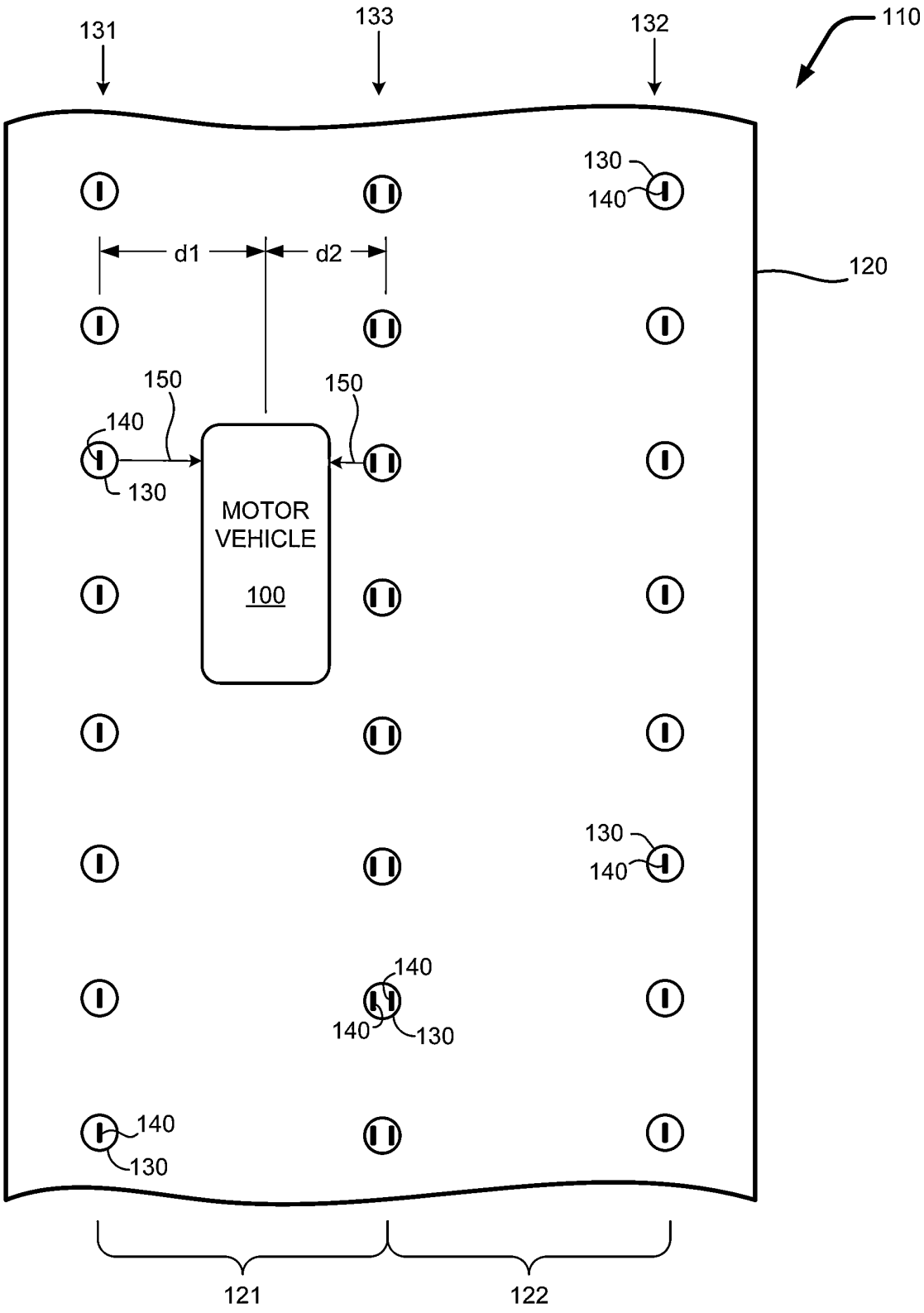
FIG. 1


131
133
132
110
130
140
d1
d2
120
150
150
140
130
MOTOR
VEHICLE
100
130
140
140
140
130
140
130
121
122

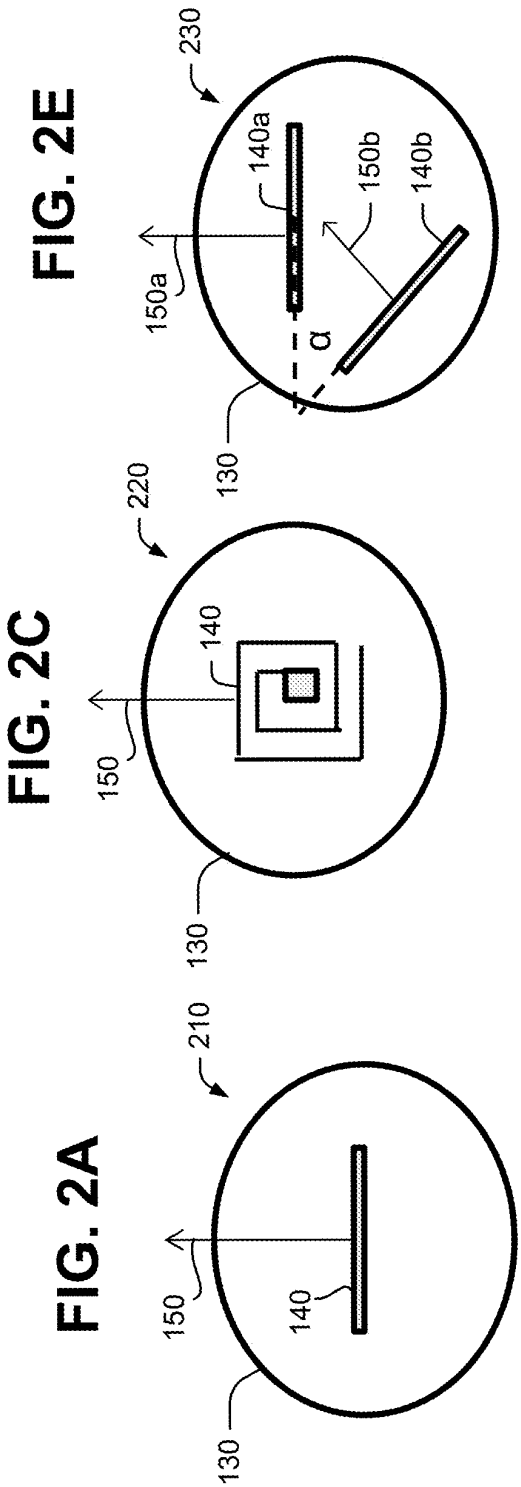


FIG. 2A
210
150
140
130

FIG. 2C
220
150
140
130

FIG. 2E
230
150a
140a
150b
140b
α
130

FIG. 2B
210
140
130

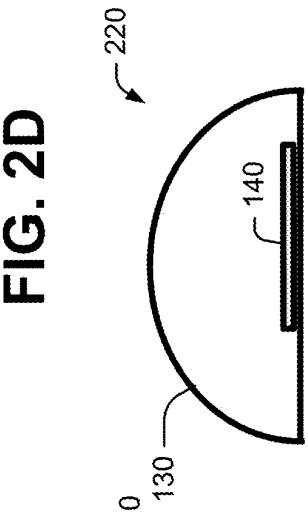


FIG. 2D
220
140
130

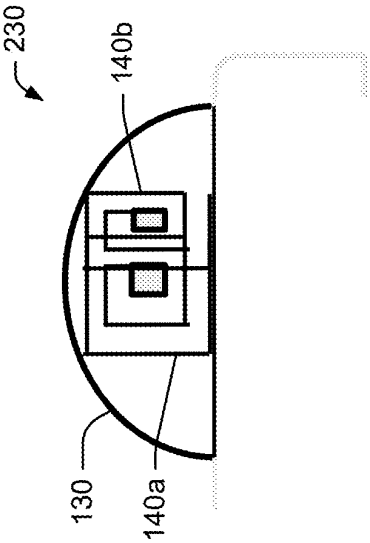
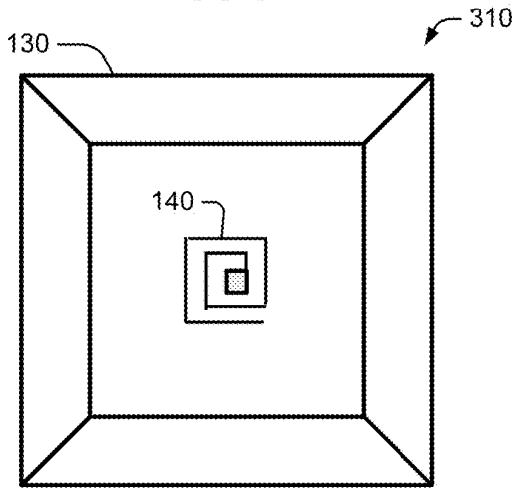


FIG. 2F
230
140b
130
140a

FIG. 3A



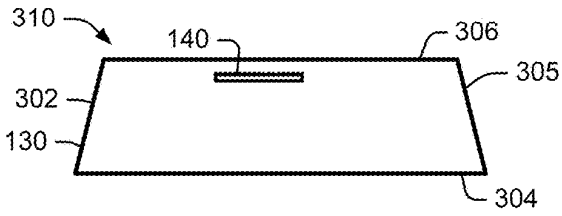
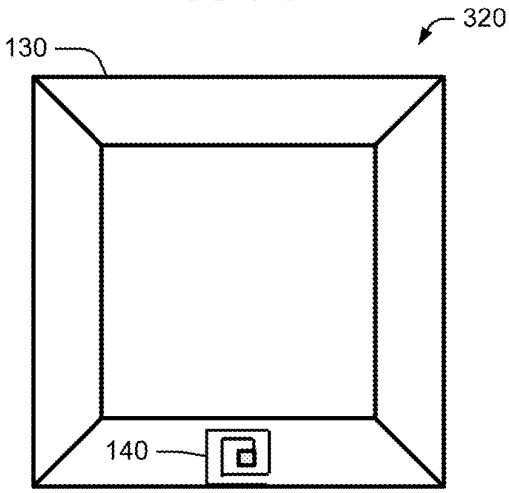


FIG. 3B

FIG. 3C



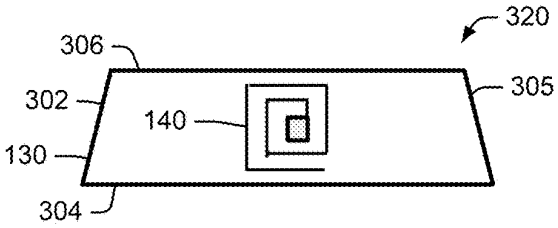


FIG. 3D

FIG. 3E

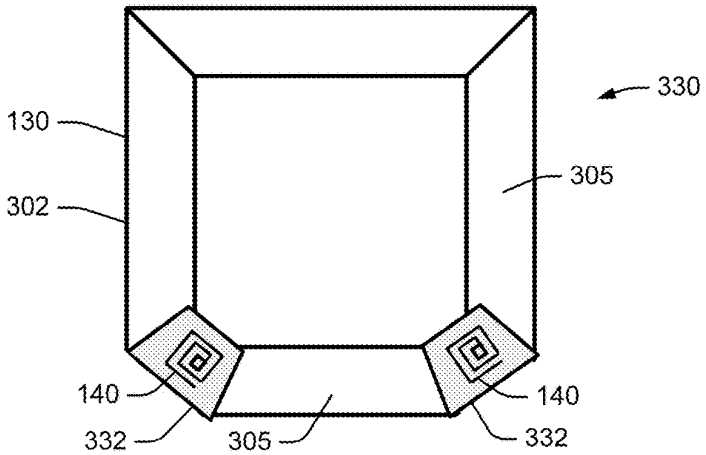


FIG. 4

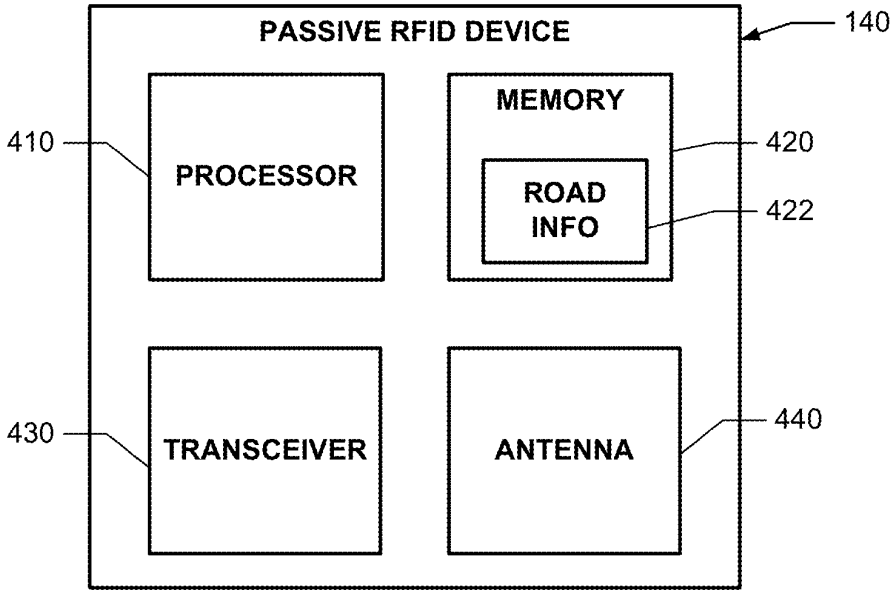

PASSIVE RFID DEVICE
140
410
PROCESSOR
MEMORY
420
ROAD INFO
422
430
TRANSCEIVER
ANTENNA
440

FIG. 5

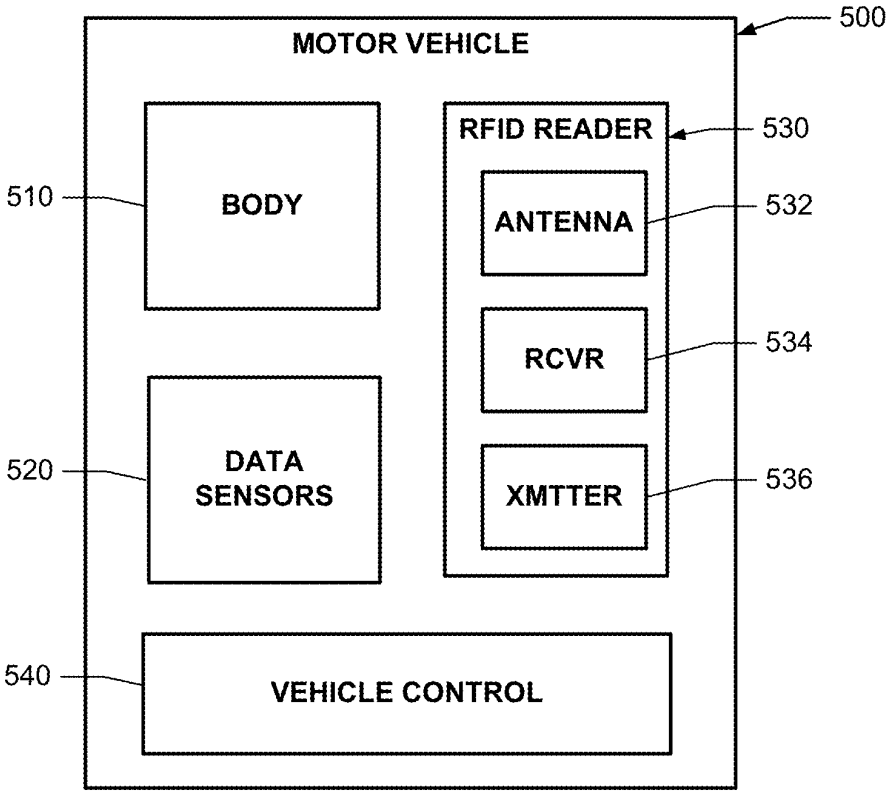

MOTOR VEHICLE
500
510
BODY
RFID READER
530
ANTENNA
532
RCVR
534
520
DATA SENSORS
XMTTER
536
540
VEHICLE CONTROL

FIG. 6

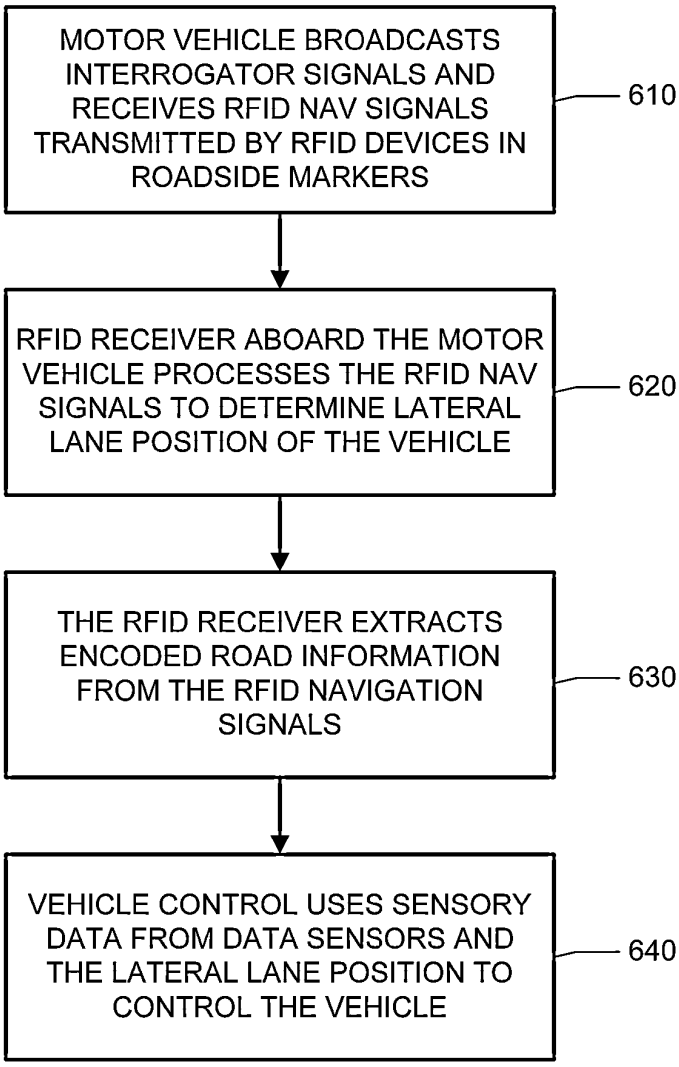

MOTOR VEHICLE BROADCASTS INTERROGATOR SIGNALS AND RECEIVES RFID NAV SIGNALS TRANSMITTED BY RFID DEVICES IN ROADSIDE MARKERS
610
RFID RECEIVER ABOARD THE MOTOR VEHICLE PROCESSES THE RFID NAV SIGNALS TO DETERMINE LATERAL LANE POSITION OF THE VEHICLE
620
THE RFID RECEIVER EXTRACTS ENCODED ROAD INFORMATION FROM THE RFID NAVIGATION SIGNALS
630
VEHICLE CONTROL USES SENSORY DATA FROM DATA SENSORS AND THE LATERAL LANE POSITION TO CONTROL THE VEHICLE
640

FIG. 7

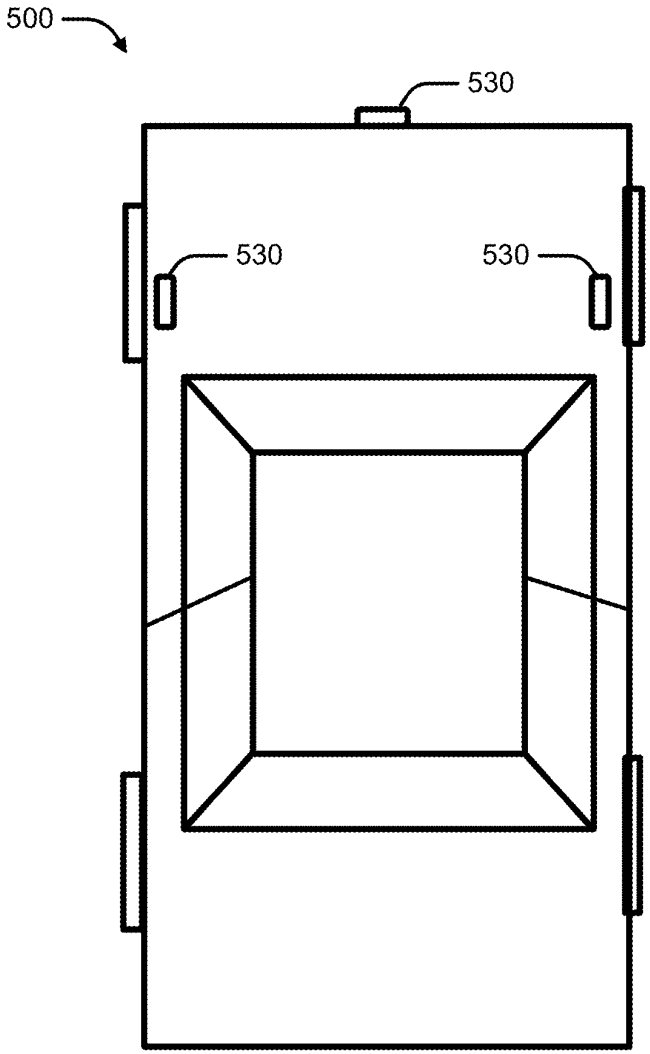
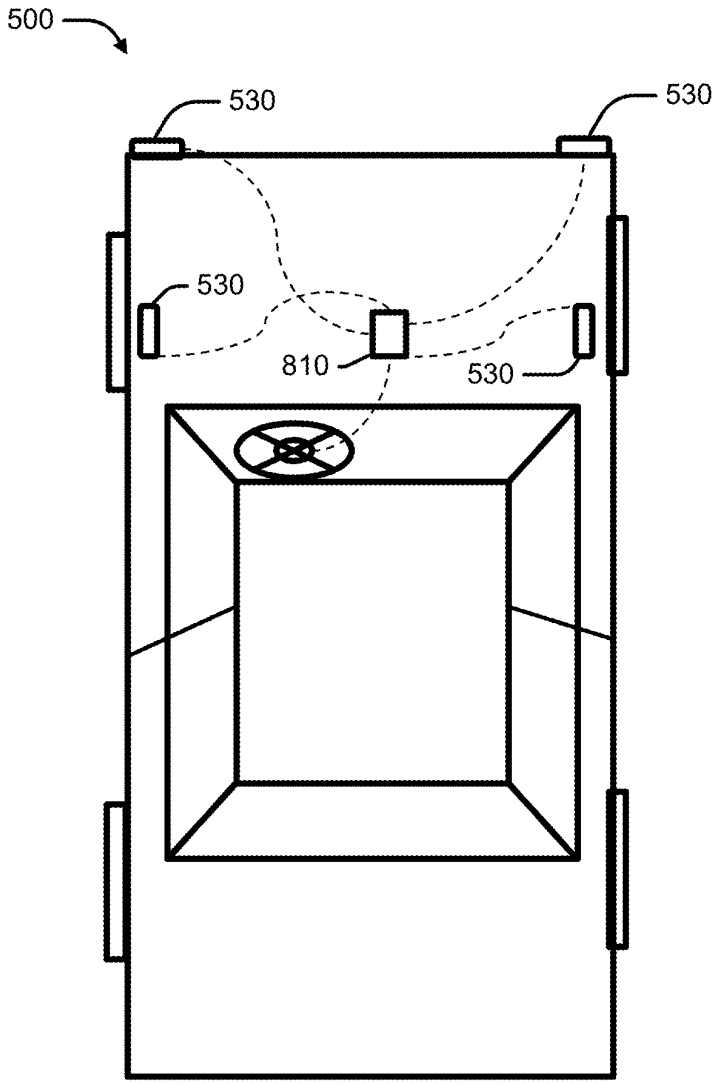


FIG. 8



NAVIGATION INFRASTRUCTURE FOR MOTOR VEHICLES

BACKGROUND

A self-driving vehicle is capable of controlling steering, acceleration, and braking without direct driver input. The input is provided by sensors such as radar, lidar, GPS, odometry, and computer vision.

However, GPS and computer vision have certain drawbacks. Thick fog, smoky conditions, and snow may make it difficult for the computer vision to generate an accurate view of roads and other surroundings. As for GPS, it has accuracy problems for moving vehicles (especially at high speeds) and vehicles in certain locations (e.g., downtown cities, and canyons). In addition, GPS is vulnerable to "spoofing" attacks, which generate false GPS signals. Spoofing attacks can create security and safety issues for self-driving vehicles.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1** is an illustration of a transit system for motor vehicles.

FIGS. **2**A and **2**B are illustrations of an apparatus for the transit system, the apparatus including a Bott's dot and an embedded RFID device at a first mounting angle.

FIGS. **2**C and **2**D are illustrations of an apparatus for the transit system, the apparatus including a Bott's dot and an embedded RFID device at a second mounting angle.

FIGS. **2**E and **2**F are illustration of an apparatus for the transit system, the apparatus including a Bott's dot and embedded first and second RFID devices at different transmission angles.

FIGS. **3**A and **3**B are illustrations of an apparatus for the transit system, the apparatus including a raised pavement reflector and a mounted RFID device.

FIGS. **3**C and **3**D are illustrations of an apparatus for the transit system, the apparatus including a raised pavement reflector and a mounted RFID device.

FIG. **3**E is an illustration of an apparatus for the transit system, the apparatus including a raised pavement reflector and two mounted RFID devices.

FIG. **4** is an illustration of a passive RFID device for the apparatus

FIG. **5** is an illustration of a motor vehicle for navigating the transit system.

FIG. **6** is an illustration of a method of operating the motor vehicle of FIG. **5**.

FIGS. **7** and **8** are illustrations of different configurations of the motor vehicle of FIG. **5**.

DETAILED DESCRIPTION

Reference is made to FIG. **1**, which illustrates a transit system **110** for motor vehicles **100**. The transit system **110** includes a road **120**, and a plurality of pavement markers **130** spaced apart along the road **120**. The pavement markers **130** may be raised, recessed, or embedded in the road **120** (or any combination thereof). Examples of the pavement markers **130** include, without limitation, Bott's dots, raised pavement reflectors, cats eyes, and delineators. The pavement markers **130** may form lane lines **131**, **132** and **133**, which define lanes **121** and **122** of the road **120**.

A plurality of RFID devices **140** are carried by the pavement markers **130**. The RFID devices **140** are also spaced apart along the road **120**. The RFID devices **140** are configured to generate and transmit RFID navigation signals **150** to motor vehicles **100** traveling down the road **120**.

As a motor vehicle **100** approaches or reaches a pavement marker **130**, it receives an RFID navigation signal **150** from the RFID device **140** carried by that pavement marker **130**. The motor vehicle **100** may process that RFID navigation signal **150** to determine a lateral lane position of the motor vehicle **100**. For instance, the motor vehicle **100** may use strength of signal ("SoS") or time of flight ("ToF") of the RFID navigation signal **150** to determine a lateral distance (d1) to a lane line **131**. If pavement markers **130** are on opposite sides of the motor vehicle **100** (as illustrated in the example of FIG. **1**) and the motor vehicle **100** receives RFID navigational signals **150** from its opposite sides, the motor vehicle **100** may use a differential ToF or a differential SoS to determine the lateral distance (d1-d2) of the motor vehicle **100** from the centerline of its lane **121**.

As the motor vehicle **100** continues down the road **120**, it receives additional RFID navigation signals **150** and computes a sequence of lateral lane positions. A motor vehicle **100** that is partially or fully automated may use these lateral lane positions to make accurate real time adjustments to the steering of the motor vehicle **100**. A vehicle **100** that is not automated may use these lateral lane positions to alert the driver that the motor vehicle **100** is drifting.

At least some of the RFID navigation signals **150** may also be encoded with road information. The encoded road information may include the position of a pavement marker **130** from the center of its associated lane, which enables the distance from the centerline to be determined from only the lateral distance d1. This is beneficial for lanes that are uneven or non-parallel.

The encoded road information may describe a lane border (which can identify the lane in which the motor vehicle **100** is located), indicate the nearest exit and distance to the nearest exit, and provide GPS information about the location of its corresponding pavement marker **130**. If the motor vehicle **100** receives RFID navigation signals **150** from opposite sides of a lane, the motor vehicle **100** may use the GPS positions of the pavement markers **130** to calculate the center lane position.

The encoded road information may further include upcoming traffic information such as distances to stop signs, traffic lights, and intersections. The encoded road information may include road topography, such as distance to changes in road curvatures and grades (e.g., the number of feet to the start of a turn with a curvature of a given radius; and the number of feet to the start of downgrade of a certain percentage). Traffic information such as road topography enables the motor vehicle **100** to know what is coming ahead, and plan for turns and other maneuvers.

Different classes of autonomous vehicles may use the RFID navigation signals **150** in different ways. In the United States, the National Highway Traffic Safety Administration (NHTSA) has proposed a formal classification system that involves five levels.

A motor vehicle **100** having a level 0 classification has no automation, but it may issue warnings. For instance, such a motor vehicle **100** may include a processor that processes a sequence of RFID navigation signals **150** to determine whether the motor vehicle **100** is drifting in its lane, and that sounds an audible alarm when drifting occurs (unless a turn signal is activated or the motor vehicle **100** otherwise indicates that it is changing lanes). The encoded road information may be used by a navigation system aboard the motor vehicle **100** (e.g., a built-in navigation system, or a mobile application such as Google Maps Navigation).

A motor vehicle **100** having a level 1 classification has function-specific automation. That is, one or more specific control functions are automated. Examples include electronic stability control or pre-charged brakes, where the motor vehicle **100** automatically assists with braking to enable the driver to regain control of the motor vehicle **100** or stop faster than possible by acting alone. A motor vehicle **100** having a level 1 classification may utilize the RFID navigations signals **150** in the same manner as a motor vehicle **100** having a level 0 classification.

A motor vehicle **100** having a level 2 classification has combined function automation. At least two primary control functions are designed to work in unison to relieve the driver of control of those functions. An example is adaptive cruise control in combination with lane centering. A motor vehicle **100** having a level 3 classification has limited self-driving automation. In such a motor vehicle **100**, a driver can fully cede control of all safety-critical functions in certain conditions. Such a motor vehicle **100** can sense when conditions require the driver to retake control and can provide a "sufficiently comfortable transition time" for the driver to do so. For instance, the steering is performed by the vehicle's control until the driver retakes control.

A motor vehicle **100** having a level 2 classification or a level 3 classification may utilize the RFID navigational signals **150** to determine lateral lane positions and use the lateral lane positions to adjust steering in real time to maintain the position of the motor vehicle **100** in its lane. Even if the lane lines are obscured by snow, fog, or other environmental factors, the vehicle position may be maintained without ceding control to the driver.

A motor vehicle **100** having a level 3 classification may use the road information encoded in the RFID navigation signals **150** to set longer warning times when encountering road situations where the motor vehicle **100** needs to cede control to the driver. For instance, if the encoded road information indicates upcoming road work and lane closures, or sharp turns in the road ahead, the motor vehicle **100** can warn the driver that it will cede control in a comfortable time period, rather than ceding in an urgent manner when it encounters road conditions that it is unable to navigate safely.

A motor vehicle **100** having a level 4 classification has full self-driving automation. Destination or navigation input is provided at the beginning of a trip, but a driver is not expected to be available for control at any time during the trip. Thus, such a motor vehicle **100** may be driverless, and it may be occupied or unoccupied. A motor vehicle having a level 4 classification may utilize the RFID navigations signals **150** in the same manner as a vehicle having a level 3 classification, except that control is not ceded at any time to a driver. Thus, a motor vehicle **100** having a level 4 classification can use the RFID navigational signals **150** to maintain vehicle lane position, and it can use the encoded road information to plan for upcoming turns (e.g., reducing speed for an upcoming sharp turn), exits, lane changes, and other driving maneuvers, and plot a driving path.

The RFID devices **140** may be passive, active or any combination thereof. Active RFID devices **140** include their own power source, or they draw power from a power source carried by its corresponding pavement marker **130**. For instance, the pavement marker **130** may carry a battery, or it may carry solar cells.

Active RFID devices **140** may periodically generate RFID navigation signals **150**. They may also have a greater transmit range than passive RFID devices **140**. Range of the RFID navigation signals **150** is typically a function of such factors as transmit power, receive sensitivity and efficiency, antenna, frequency, device orientation, and surroundings.

Passive RFID devices **140** harvest power from interrogator signals to generate and transmit the RFID navigation signals **150**. (As used herein, passive RFID devices **140** include semi-passive devices, which also harvest power from the interrogator signals.) The range, strength and frequency of the interrogator signals may depend in part upon speed of the motor vehicle **100** and distance (along a lane) between pavement markers **130**. The interrogator signals may be transmitted in a forward direction. For the transit system **110** of FIG. **1**, as a motor vehicle **100** traveling along the road **120** may broadcast interrogator signals in a forward direction. An RFID device **140** ahead of the motor vehicle **100** receives an interrogator signal and responds by transmitting an RFID navigation signal **150**. The motor vehicle **100** receives the navigation signal **150** as it approaches or reaches the RFID device **140**.

At any given time, the motor vehicle **100** may receive RFID navigation signals **150** from more than one RFID device **140**. As mentioned above, the motor vehicle **100** may receive RFID navigation signals **150** on opposite sides. The motor vehicle **100** may receive RFID navigation signals **150** from an adjacent pavement marker **130** and at least one pavement marker **130** further up the road **120**.

There is no need for each pavement marker **130** to carry an RFID device **140**. If pavement markers **130** are clustered together, only one or a few of the pavement markers **130** in the cluster may carry an RFID device **140**. Even if the pavement markers **130** are not clustered, every n^{th} pavement marker **130** along a lane may carry an RFID device **140** (where integer n>1).

The example of FIG. **1** shows a road **120** having two lanes **121** and **122**, two outer lane lines **131** and **132** of pavement markers **130**, and a middle lane line **133** of pavement markers **130**. However, the transit system **110** is not so limited. Other roads **120** may have different numbers of lanes and lane lines. For instance, a road **120** might have a single lane and a single line of pavement markers **130**.

More than one RFID device **140** may be carried by a pavement marker **130**. For instance, the pavement markers **130** forming the middle lane line **133** may carry two RFID devices **140**: one for transmitting an RFID navigation signal **150** into the left lane **121**, and the other for transmitting an RFID navigation signal **150** into the right lane **122** (in contrast, each of the pavement markers **130** forming the outer lane lines **131** and **132** may carry only a single RFID device **140**). The RFID device **140** may direct their RFID navigation signals **150** at an angle that maximizes the signal from the desired lane, and minimizes the signal from the undesired lane.

The transit system **110** is not limited to pavement markers **130**. A pavement marker **130** is but one type of roadside marker. Other types of roadside markers may be used instead of, or in addition to, the pavement markers **130**. For instance, the RFID devices **140** may be carried by roadside markers such as guard rails and k-rails.

FIGS. **2**A to **2**F illustrate three different examples **210**, **220** and **230** of an apparatus including a pavement marker **130** and at least one embedded RFID device **140**. In each example **210**, **220** and **230**, the pavement marker **130** is a Bott's dot. A typical Bott's dot is semi-hemispherical. A flat surface of the Bott's dot is secured to the road **120**. At least one RFID device **140** is embedded within the Bott's dot. For illustrative purposes, FIGS. **2**A-**2**F show the Bott's dots as being made of translucent material, whereby the RFID devices **140** are visible. In practice, however, the Bott's dots

are typically made of ceramic or plastic. RF signals penetrate both ceramic and plastic in the length scales of Bott's dots.

Orientation of the RFID device **140** within the Bott's dot may be characterized by a mounting angle. The RFID device may be oriented parallel to (facing) the flat surface of the Bott's dot (mounting angle=0 degrees), it may be oriented perpendicular (edge-wise) to the flat surface (mounting angle=90 degrees), or it may be oriented at some mounting angle between 0 and 90 degrees.

The pavement marker **130** may have markings to allow it to be installed at a known orientation with respect to the lane line. In this known orientation, the RFID navigation signal **150** is transmitted perpendicular to the lane line and across the road (as illustrated in FIG. **1**). The RFID navigation signal **150** is received as the motor vehicle **100** reaches the pavement marker **130**. At this orientation, the RFID device **140** is said to have a transmission angle of 0 degrees. At a non-zero transmission angle, the RFID navigation signal **150** is directed towards the motor vehicle **100** as the motor vehicle **100** is approaching (but has not yet reached) the pavement marker **130**.

FIGS. **2**A and **2**B illustrate top and side views, respectively, of the first example **210**. The RFID device **140** is oriented at a mounting angle of 90 degrees, and its transmission angle is roughly 0 degrees.

FIGS. **2**C and **2**D illustrate top and side views, respectively, of the second example **220**. The RFID device **140** is oriented at a mounting angle of 0 degrees, and the transmission angle is roughly 0 degrees.

FIGS. **2**E and **2**F show top and side views, respectively, of the third example **230**, in which the Bott's dot carries a first RFID device **140***a* having a short transmission range, and a second RFID device **140***b* having a long transmission range. The first RFID device **140***a* directs its RFID navigation signal **150***a* at a transmission angle of zero degrees, and the second RFID device directs its navigation signal **150***b* at a non-zero transmission angle (α). The navigation signal **150***a* transmitted by the first RFID device **140***a* is received by motor vehicles **100** close to the pavement marker **130** and are used primarily to determine the lateral lane position. The RFID navigation signal **150** transmitted by the second RFID device **140***b* is received by motor vehicles **100** further away and are used primarily to provide encoded road information.

In North America, the first RFID device **140***a* may transmit at, for example, 902-928 MHz UHF ISM band, which can be adjusted to cover about 1 to 12 meters; and the second RFID device **140***b* may transmit at 433 MHz, which can be adjusted to cover about 1 to 100 meters. In Europe, the first RFID device **140***a* may transmit at 865-868 MHz UHF ISM band, and the second RFID device **140***b* may transmit at 433 MHz.

FIGS. **3**A to **3**E illustrate three additional examples **310**, **320** and **330** of an apparatus including a pavement marker **130** and at least one embedded RFID device **140**. In each additional example **310**, **320** and **330**, the pavement marker **130** is a raised pavement reflector. The raised pavement reflector includes a reflector body **302** that is shown as being made of a translucent material (for illustrative purposes), but is typically made of plastic or ceramic. A bottom planar surface **304** of the reflector body **302** is secured to the road. The reflector body **302** also has angled surfaces **305** and an upper planar surface **306**. The angled surfaces **305** of the reflector body **302** may be coated with reflective material, or reflectors may be epoxied to the angled surfaces **305**. The raised pavement reflector may also include a lens or sheeting that covers the angled surfaces **305**. The lens or sheeting enhances visibility by reflecting automotive headlights. At least one RFID device **140** may be mounted beneath the angled and upper surfaces **305** and **306**. If reflectors are epoxied to the reflector body **302**, an RFID device **140** may instead be embedded in the epoxy.

FIGS. **3**A and **3**B illustrate top and side views, respectively, of the first additional example **310**. The RFID device **140** is mounted underneath the upper planar surface **306** at a mounting angle of roughly 0 degrees (roughly parallel to the upper planar surface **306**). The position of the RFID device **140** shown in FIGS. **3**A and **3**B is not limiting. The RFID device **140** may be mounted at another mounting angle and may be positioned at another distance from within the reflector body **302**.

FIGS. **3**C and **3**D illustrate top and side views, respectively, of the second additional example **320**. The RFID device **140** is surface mounted underneath one of the angled surface **305** of the reflector body **302**. Mounting angle is between 0 and 90 degrees.

The raised pavement reflector may have a rectangular geometry, but it is not so limited. For instance, corners of the raised pavement reflector may be cut on the corners facing oncoming motor vehicles **100**.

FIG. **3**E illustrates a top view of the third additional example **330**, in which the reflector body **302** is cut on corners **332** facing oncoming motor vehicles **100**. An RFID device **140** is mounted underneath each cut corner **332** The RFID devices **140** are oriented to face adjacent lanes. This creates a higher signal to and from the antenna.

Another example of a pavement marker **130** (not illustrated) is a "cat's eye," which may include two pairs of reflective glass spheres set into a flexible white rubber dome, mounted in a metal housing. The rubber dome may be occasionally deformed by passing traffic. One or more RFID devices **140** may be embedded in the spheres or attached to the metal housing.

Another example of a pavement marker **130** (not illustrated) is a "delineator." A delineator is a tall pylon (similar to a traffic cone or bollards) mounted on a road surface, or along an edge of a road. Delineators are typically used to channelize traffic. One or more RFID devices **140** may be attached to the pylon.

The RFID devices **140** may be embedded in or mounted to the pavement markers **130** at the time of manufacture of the pavement markers **130**. However, pavement markers **130** already on a road may be retrofitted to include the RFID devices **140**. A pavement marker **130** may be retrofitted, for instance, by boring a small hole, embedding the RFID device **140** in the hole, and either filling the hole with epoxy or covering the hole with tar or another material.

As mentioned above, the RFID devices **140** may be carried by roadside markers such as guard rails and k-rails. The RFID devices **140** may be attached to the surface of k-rails or embedded in the k-rail material at the time of manufacture. The RFID devices **140** may be mounted on housings on the posts of the guard rails, or on another surface. The RFID devices **140** may be embedded in the posts, for example, by boring holes in the posts and inserting the RFID devices **140**, with or without device housings.

Reference is made to FIG. **4**, which illustrates functional components of a passive RFID device **140** including a processor **410**, machine-readable memory **420**, transceiver **430**, and antenna **440**. Road information **422** may be stored in the memory **420**. The transceiver **430** receives an interrogator signal, which powers the processor **410** to generate an RFID navigation signal (including encoded road information), and send the RFID navigation signal to the trans-

ceiver **430**. The transceiver **430** then transmits the RFID navigation signal via the antenna **440**. A directional antenna **440** is preferred, but the antenna **440** may be isotropic. Consider the RFID devices **140** along the middle lane line **133** in FIG. **1**. They made include two directional antennae or a single isotropic antenna.

The RFID devices **140** may be configured to receive messages or data from RFID printers, and store information contained in those messages or data. For instance, if any exit is closed due to maintenance, this exit closure information may be wirelessly downloaded or printed to the RFID devices in those pavement markers **130** preceding the closed exit.

GPS location may also be printed in the memory **420** of the RFID device **140**. By printing the GPS location on the RFID device **140**, spoofing can be thwarted because the RFID information is local, and redundant. If a GPS satellite signal is jammed and emulated with false information, the observed GPS satellite information will not agree with the printed GPS information.

Reference is now made to FIG. **5**, which illustrates a motor vehicle **500**. Examples of the motor vehicle **500** include, but are not limited to, an automobile, motorcycle, utility vehicle, truck, and transport vehicle (e.g., bus, passenger van).

The motor vehicle **500** includes a body **510**, data sensors **520**, at least one RFID reader **530**, and a vehicle control **540**. (Other elements of the motor vehicle **500**, including the engine and drive train, are not illustrated.) In the case of a motorcycle, the body **510** includes a frame. In the case of an automobile, the body **510** includes a chassis and an outer shell attached to a chassis.

The vehicle control **540** may be automated (resulting in an NHTSA classification of 1 or greater), or it may not be automated (resulting in an NHTSA classification of 0). A vehicle having a level 4 classification may be driverless.

The data sensors **520** generate sensory data for the motor vehicle control **540**. Examples of the data sensors **520** include, but are not limited to, radar, lidar, GPS, odometry, and computer vision. The vehicle control **540** may use this sensory data for various functions including, but not limited to, distinguishing between different cars on the road, identifying signs, planning appropriate navigation paths, and collision avoidance.

The RFID reader **530** includes an antenna **532** mounted to the body **510** at a location for capturing the RFID navigation signals during movement of the motor vehicle **500**. The RFID reader **530** further includes an RFID receiver **534** for processing the captured RFID navigation signals to determine a lateral lane position of the motor vehicle **500** during movement of the motor vehicle **500**. The RFID receiver **534** may also extract encoded road information from the captured RFID navigation signals.

The RFID reader **530** may be active or passive. If the RFID devices are active, the RFID reader **530** may be passive or active. If the RFID devices are passive, then the RFID reader **530** may be active. The vehicle **500** may supply power to an RFID reader **530** that is active. An RFID reader **530** that is active may also have a transmitter **536** for transmitting interrogator signals via the antenna **532** during movement of the motor vehicle **500**.

The RFID reader **530** of FIG. **5** is illustrated in terms of functionality. The receiver **534** and the transmitter **536** may be integrated into a single transceiver, or they may be implemented as separate components. The receiver **534** and the transmitter **536** may have separate processing capability, or they may share a common processor. The RFID reader **530** may contain more than one receiver and one transmitter, which may operate at the same or different frequencies.

Additional reference is made to FIG. **6**, which illustrates a method in which the motor vehicle **500** is controlled to move along a road marked with roadside markers. At least some of the roadside markers carry active RFID devices **140** and/or passive RFID devices that broadcast RFID navigation signals when interrogated.

At block **610**, as the motor vehicle **500** moves along the road in a forward direction, it broadcasts interrogator signals and it receives RFID navigation signals transmitted by the interrogated RFID devices **140**. The interrogator signal may be broadcast continuously or in timed radio pulses.

At block **620**, the RFID receiver **534** processes the RFID navigation signals to determine lateral lane position of the motor vehicle **500**. If the RFID navigation signals are received from only one side of a lane, absolute distance from a lane line may be determined. If the RFID navigation signals are received from opposite sides of a lane, a differential signal can be used to determine the distance from the lane's centerline.

The processing of the RFID navigation signals may also include measures to prevent false information or interference from other vehicles on the road. For instance, the motor vehicle **100** has an identifier and/or identifying handshaking signal (e.g., a series of short or long pulses), which are reflected by the roadside markers. Thus, the RFID reader **530** only listens to the navigation signal returned in response to the handshaking signal.

At block **630**, the RFID receiver **534** may also extract any encoded road information from the RFID navigation signals.

At block **640**, the vehicle control **540** uses sensory data from the data sensors **520** and the lateral lane position from the RFID reader **530** to control the motor vehicle **500**. For example, an automated vehicle control **540** can use the lateral lane position to steer the motor vehicle **500** (e.g., center the motor vehicle **500** in a lane), and it can use the road information to plan for upcoming maneuvers and plot a driving path. The vehicle control **540** can use information such as identification of next exit, and distance to next exit, to safely execute lane changes to position the motor vehicle **500** to take the exit when it approaches the exit. It can use information such as lane closures to navigate the motor vehicle **500** to lanes that are open to traffic.

In some instances, the RFID reader **530** may determine optimal frequency or period of interrogation as a function of distance between pavement markers and speed of the motor vehicle **500**. The distance may be known in advance, or the distance may be determined in real time (e.g., from the time of flight or GPS location information broadcast from the roadside markers). If the roadside markers are x feet apart, and the motor vehicle **500** is moving at a speed of y feet per second, then the interrogation signal may be broadcast at an optimal period of once per x/y seconds. If the distance is not known in advance, the interrogation signals may be broadcast at a high frequency to determine the position of the highest signal detected from the roadside markers, and then adjust the interrogation frequency to the optimal frequency.

The motor vehicle **500** may have one or more of the RFID readers **530** for generating the interrogation signals and capturing the RFID navigation signals. Interrogation by multiple RFID readers **530** delivers more power to passive RFID devices. Interrogation by multiple RFID readers **530** also allows greater control of the angle of the interrogation signal relative to the roadside markers. Whereas a single RFID reader **530** at the front center of the motor vehicle **500** is positioned forward to interrogate both sides of the lane,

RFID readers **530** on opposite sides of the motor vehicle **500** may be angled to see the roadside markers coming ahead and can anticipate locations and changes in lane curvature.

FIGS. **7** and **8** illustrate different configurations of the motor vehicle **500**. In the configuration of FIG. **7**, an RFID reader **530** is mounted to the front center of the motor vehicle **500**, and two other RFID readers **530** are mounted on the opposite sides of the motor vehicle **500** (e.g., in wheel wells of the motor vehicle **500**). In the configuration of FIG. **8**, two RFID readers **530** are mounted to the front of the motor vehicle **500**, and two other RFID readers **530** are mounted on the opposite sides of the motor vehicle **500**. These configurations enable multiple interrogations in a forward direction.

In the configuration of FIG. **8**, the RFID readers **530** do not process the received RFID signals. Instead, the RFID readers **530** are electrically connected to a shared processor **810**, which performs the processing. The shared processor **810** may or may not share other vehicle functions such as steering, braking, navigation calculation, GPS positioning, etc.

The motor vehicle **500** is not limited to the configurations illustrated in FIGS. **7** and **8**. In another configuration, the motor vehicle **500** may have only a single RFID reader **530** located at the front. In yet another configuration, the motor vehicle **500** may have only RFID readers **530** on opposite sides. In still another configuration, the motor vehicle **500** may have one or more RFID readers **530** mounted at the back of the motor vehicle **500**. Other configurations may have additional RFID readers **530** at strategic locations for better signal reception.

In other configurations of the motor vehicle **500**, the RFID readers **530** may be placed at other positions from which they can interrogate and receive the RFID navigation signals from the RFID devices in the roadside markers. For instance, there may be ports intentionally designed into the body **510** of the motor vehicle **500** for the express purpose of mounting the RFID readers **530**.

Thus disclosed is an infrastructure that can immediately provide local position information to autonomous motor vehicles. The infrastructure utilizes existing roadside markers, with only minor modifications to those roadside markers. It does not depend upon uniform width of the roads.

The infrastructure provides advantages over computer vision and GPS. The RFID environment is better suited than GPS for detecting lateral lane position of fast-moving vehicles. It is better suited than computer vision for detecting lateral lane position in inclement weather and other conditions (e.g., snow, sand, smoke, thick fog, white out conditions) that obscure lane lines and other road details. Thus, the infrastructure creates much greater safety for autonomous vehicles in both normal and difficult conditions.

A transit system herein is not limited to standard RFID devices **140**. RFID devices **140** that differ from the standard may be used. For instance, the non-standard RFID device operates similar to a standard RFID device, but may communicate over non-standard radio frequencies (e.g., special frequencies slotted for autonomous navigation). In this case the first and second RFID devices **140***a* and **140***b* may broadcast at frequencies to be reserved by the International Organization for Standardization for navigational systems. The RFID devices **140** may have different nomenclature. Other aspects of the standard RFID device may be altered including, but not limited to, range, memory size, and memory configurations.

A transit system herein is not even limited to RFID devices **140**. The RFID devices **140** described herein are but one type of RF device. The roadside markers may carry other types of RF devices instead of, or in addition to, RFID devices **140**. These other types of RF devices include, but are not limited to, WiFi devices, Bluetooth devices, and ZigBee® devices.

The RF devices generate and transmit RF navigation signals. The RFID navigation signal **150** is a type of signal generated and transmitted by RFID devices **140**.

The invention claimed is:

1. An apparatus comprising:

a raised pavement marker configured to be mounted to a road at a lane line of a lane at known orientation with respect to the lane line; and

an RF device carried by the raised pavement marker, the device configured to transmit directional RF navigation signals and positioned relative to the known orientation to transmit the signals across the lane in a direction that is substantially normal to the lane line.

2. The apparatus of claim **1**, wherein the RF device is a passive RFID device that is configured to respond to an interrogator signal.

3. The apparatus of claim **1**, wherein the RF device is configured to include encoded road information in the RF navigation signals.

4. The apparatus of claim **1**, wherein at least one additional RF device is carried by the pavement marker, the at least one additional device also configured to generate RF navigation signals.

5. The apparatus of claim **1**, further comprising a second RF device carried by the roadside marker, wherein the second RF device has a non-zero transmission angle.

6. The apparatus of claim **1**, wherein the RF device is mounted to the pavement marker at a non-zero degree mounting angle.

7. The apparatus of claim **1**, wherein the raised pavement marker includes a Bott's dot, the Botts dot having markings for installation at the known orientation and wherein the RF device includes a passive RFID device embedded within the Bott's dot relative to the markings.

8. The apparatus of claim **1**, wherein the raised pavement marker includes a raised pavement reflector, and wherein the RF device includes a passive RFID device mounted underneath a surface of the raised pavement reflector.

9. The apparatus of claim **1**, wherein the RF device includes memory encoded with road information, the RFID device configured to generate the RF navigation signal including the encoded road information.

10. A system for lateral lane positioning of vehicles on a road, the system comprising:

a plurality of raised pavement markers mounted to the road at lane lines; and

a plurality of passive RFID devices embedded within at least some of the pavement markers, each of the passive RFID devices configured to transmit a directional RFID navigation signal across the road at a transmission angle of only zero degrees with respect to its associated lane line.

11. The system of claim **10**, wherein the pavement markers include Bott's dots, and wherein the RF devices are embedded within at least some of the Bott's dots.

12. The system of claim **10**, wherein the pavement markers include raised pavement reflectors, and wherein the RF devices are within at least some of the raised pavement reflectors.

13. The system of claim **10**, wherein at least some of the RF devices include memory encoded with road information

and are configured to generate the RF navigation signals having the encoded road information.

14. The system of claim **10**, wherein the passive RFID devices are mounted to their raised pavement markers at a non-zero degree mounting angle.

15. The system of claim **10**, wherein each raised pavement marker is configured with a known orientation with respect to its associated lane line, and wherein each device is positioned relative to the known orientation to transmit the directional RFID signal at the about zero degree transmission angle.

16. A motor vehicle comprising:

a body;

an RFID antenna mounted to the body at a location for receiving RFID navigation signals during movement of the vehicle;

an RFID receiver, mounted on the body, the receiver configured to broadcast interrogation signals in timed radio pulses as a function of distance between pavement markers and speed of the vehicle, and receive RFID navigation signals in response to the interrogation signals, the receiver further configured to process the received RFID navigation signals to determine a sequence of lateral lane distances of the vehicle; and

an vehicle control responsive to changes in the sequence of lateral lane distances for lateral lane positioning of the vehicle.

17. The motor vehicle of claim **16**, wherein the motor vehicle has an NHTSA classification level of at least 2, and wherein the vehicle control uses a sequence of the lateral lane distance to adjust steering in real time to maintain lane position of the motor vehicle.

18. The motor vehicle of claim **16**, wherein the motor vehicle has an NHTSA classification level of 4, and wherein the vehicle control uses a sequence of the lateral lane distance to adjust steering in real time to maintain lane position of the motor vehicle, and uses encoded road information in the RF navigational signals to plan for driving maneuvers and to plot driving paths.

19. The motor vehicle of claim **16**, wherein the motor vehicle has an NHTSA classification level of no more than 1, and wherein the vehicle control uses a sequence of the lateral lane distance to alert a driver when the motor vehicle is drifting.

20. The motor vehicle of claim **16**, wherein the antenna is mounted to the body at one of a front and a wheel well of the body.

21. A method comprising controlling a motor vehicle to move along a road having pavement markers along a lane line of a lane of the road, at least some of the pavement markers carrying RFID devices that, when interrogated, transmit directional RFID navigation signals across the lane in a direction normal to the lane line; wherein controlling the motor vehicle includes:

broadcasting interrogation signals in timed radio pulses as a function of distance between the pavement markers and speed of the vehicle;

receiving the RFID navigation signals as the vehicle moves along the lane;

processing the received RFID signals to determine a sequence of lateral distances from the lane line; and

steering the vehicle in response to changes in the sequence of lateral distances to avoid vehicle drift.

22. The method of claim **21**, further comprising extracting encoded road information from the received RFID navigation signals and using the encoded road information to plan upcoming driving maneuvers.

23. The method of claim **21**, wherein if the distance between the pavement markers is not known, the interrogation signals are broadcasted at a high frequency to determine a maximum signal from the pavement markers, and then that information is used to adjust the timed pulses to coincide with the spacing and speed of the vehicle.

24. The system of claim **10**, wherein the plurality of pavement markers are along one side of a lane of the road, the system further comprising a plurality of additional pavement markers spaced apart along an opposing side of the lane and a plurality of additional RF devices carried by the additional pavement markers, wherein each of the additional RF devices is configured to transmit a directional RF navigation signal across the lane at a zero degree transmission angle.

25. The motor vehicle of claim **16**, wherein:

the RFID receiver is configured to receive the RFID navigation signals from opposite sides of the motor vehicle, and use a differential time of flight or a differential strength of signal to determine the sequence of lateral lane distances.

26. The method of claim **21**,

wherein the lane line is at one side of the lane;

wherein the road also has additional pavement markers along a lane line at an opposite side of the lane, at least some of the additional pavement markers carrying additional RFID devices that transmit additional directional RFID navigation signals across the lane;

wherein the method further includes interrogating and receiving the additional RFID navigation signals from the additional RFID devices; and processing the received additional RFID signals to determine a sequence of lateral distances from the lane line at the opposite side; and

wherein the vehicle is instead steered in response to differences in the lateral distances of both sequences to avoid vehicle drift.

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