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VEHICLE COMMUNICATION SYSTEM USING STAGGERED COMMUNICATION CYCLES TO REDUCE INTERFERENCE

CROSS-REFERENCE TO RELATED APPLICATIONS

This application is related to and claims priority from Japanese Patent Application No. Hei. 7-33524, incorporated herein by reference.

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to a vehicle communication system including a road-installed device having a plurality of antenna units that set predetermined communication areas on a road, and a vehicle-installed device provided in a vehicle for communicating with the road-installed device when the vehicle passing through one of the communication areas.

2. Description of Related Art

In a typical conventional automatic tolling system for toll roads, such as express highways, a vehicle is provided with a communication device (i.e., a vehicle-installed device) that stores a pre-registered identification number or the like, and a place for tolling is provided with another communication device (i.e., a road-installed device) for, when the vehicle passes through a communication area determined by the road-installed

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recognize that the vehicle having the registered identification number has passed through the area and stores the event, in order to enable the toll to be collected by other means on the basis of the data recorded.

However, all such conventional systems generally are designed for a single traffic lane and therefore have some difficulties in application to a typical road having a plurality of lanes. A toll data communication system adapted to a road with a plurality of lanes is disclosed in, for example, Japanese Laid-Open Patent Publication No. Hei. 5-324967.

This road toll collecting system using non-contact IC cards is designed to improve the reliability in wireless communications between a road-installed device and non-contact IC cards in a check barrier. In this system, a road device provided in a check barrier is connected to a plurality of antennas that are arranged so that the communication areas of the antennas are shifted from each other in the vehicle traveling direction with respect to each lane, in order to increases the occasions in which communication between the road device and the non-contact IC cards of the vehicles is possible.

This construction eliminates the need for performing an automatic tolling procedure with the individual lanes being separated in a toll road, such as a express highway, where tolling is needed, but performs the automatic tolling procedure for the plurality of lanes as they exist, thereby reducing the manpower required and reducing the incidence of traffic congestion occurring at toll booths.

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However, because the above-described conventional system requires that antennas be arranged over a long distance, it is necessary that the antennas be usable even in narrow installation spaces. To avoid this, a construction that employs a similar method but allows the antennas to be arranged over a reduced distance is as follows.

In an example construction, a plurality of antenna units are provided so that communication areas are provided corresponding to individual lanes of a road and so that the communication area of each antenna unit overlaps the neighboring communication area, so that the communication areas of the antenna units cover the entire width of the road without any communication blind area. Different transmission timings are determined for the antenna units whose communication areas overlap each other, and different signal frequencies are determines for the antennas within a range in which vehicle-installed devices can receive the signals, thus enabling reliable communications.

However, because of an expected drawback as described below, this construction has a problem in that the communications between a vehicle-installed device and an antenna unit may fail. An example construction where such a drawback occurs will be described with reference to FIGS. 15 and 16A - 16D.

FIG. 15 shows a gantry 1 that extends over the width of a road on which vehicles travel from the bottom to the top of the sheet of the drawing. The gantry 1 is provided with two antenna units 2, 3 that define communication areas 4, 5,

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respectively. The communication areas 4, 5 have an overlap area D in common. If a device 6 installed in a vehicle passes through a peripheral edge area of one of the communication areas, at least one of the antenna units 2, 3 will communicate with the vehicle-installed device. The antenna units 2, 3 transmit pilot signals and interrogation signals and unmodulated carrier waves over the communication areas 4, 5 at different frequencies and different transmission timings.

When the device 6 installed in the vehicle passing though the communication area 4 or 5 receives a pilot signal from the antenna unit 2, the vehicle-installed device 6 determines the antenna unit 2 as a fixed communication party to continue further communications and remains unresponsive to pilot signals from the other antenna unit 3 until the communications end. This construction thus avoids the drawback that when the vehicle-installed device 6 passes through the overlap area D, the device 6 receives pilot signals from both the antenna units 2, 3, thus experiencing radio interference.

However, if the vehicle-installed device 6 is installed in a small vehicle, such as a motorcycle, and if the device 6 and another device 7 also installed in a small vehicle travel side-by-side and simultaneously enter an overlapping area D, interference may occur as described below, depending on the contents of communications.

Since the two antenna units 2, 3 are next to each other and their communication areas 4, 5 overlap each other in the area D, the antenna units 2, 3 are controlled so that the timing of

transmission of a pilot signal PLT or an interrogation signal RC or WC from the antenna unit 2 is shifted from the timing of transmission of a pilot signal PLT or an interrogation signal RC or WC from the antenna unit 3 by half (T/2) of the cycle T of the transmission of the antenna units 2, 3 (see FIGS. 16A and 16D).

When the two vehicle-installed devices 6, 7 enter the overlapping area D, the devices 6, 7 receive a pilot signal PLT1 from the antenna unit 2, which starts transmission earlier than the antenna unit 3. The vehicle-installed devices 6, 7 generate pilot response signals RSP1, RSP1' corresponding to the pilot signal PLT1, and transmit the pilot response signals RSP1, RSP1' by modulating the signals when reflecting an unmodulated carrier wave from the antenna unit 2 (see FIGS. 16B and 16C).

Since the antenna unit 2 receives the pilot response signal RSP1 from the vehicle-installed device 6, which is closer than the vehicle-installed device 7, the antenna unit 2 transmits an interrogation signal RC1 generated for the vehicle-installed device 6 (see FIG. 16A). On the other hand, the vehicle-installed device 7 does not receive an interrogation signal generated therefor although it has transmitted the pilot response signal RSP1'. Thus, the vehicle-installed device 7 will respond to a pilot signal PLT2 from the antenna unit 3.

While the vehicle-installed devices 6, 7 continue the communications with the antenna units 2, 3, respectively, a time Δt may occur in which the response signal RD2 transmitted to the antenna unit 3 by the vehicle-installed device 7 as a result of the data read from a storage unit of the device 7 in response to

the interrogation signal RC2 overlaps the response signal WD1 transmitted to the antenna unit 2 by the vehicle-installed device 6 (see FIGS. 16B and 16C).

However, if the two vehicle-installed devices 6, 7 simultaneously transmit response signals WD1 and RD2, the signals interfere with each other and then the antenna units 2, 3 cannot separately receive the response signals WD1 and RD2. Thus, the antenna units 2, 3 are in an interference state and cause a problem in that neither of the signals can be properly received.

SUMMARY OF THE INVENTION

The present invention is intended to solve the above stated problems. It is an object of the invention to provide a vehicle communication system in which, if a plurality of vehicle-installed devices are passing through an overlapping communication area, communications between the vehicle-installed devices and antenna units are unfailingly enabled.

A vehicle communication system according to a first aspect of the present invention includes a plurality of antenna units provided corresponding to a plurality of communication areas for performing communications by transmitting interrogation signals in a predetermined cycle and for receiving a response signal from the communication areas; a vehicle-installed device for setting different timings of transmitting interrogation signals for at least those of the plurality of antenna units whose communication areas neighbor and overlap each other so that the timings are shifted from each other by half of the

transmission cycle, and for identifying a vehicle passing through one of the communication areas on the basis of a signal received; a vehicle-installed device provided in a vehicle for transmitting a response signal when receiving an interrogation signal from one of the antenna units and for, when receiving an interrogation signal again from the same antenna unit, transmitting an interrogation response signal, so as to perform communications; and a communication control unit provided in the vehicle-installed device for setting a timing of transmitting a response signal for the interrogation signal to a time point at which time at least a predetermined length of time elapses, the time point being within the transmission cycle of the interrogation signal.

According to this aspect of the invention, the antenna units transmit interrogation signals over the communication areas in the predetermined cycle in such a manner that the transmission timings of neighboring antenna units are shifted from each other by half the cycle. When a vehicle-installed device of a traveling vehicle enters a communication area, the vehicle-installed device transmits a response signal to the antenna unit from which the device has receives an interrogation signal, and perform further communications with that antenna unit. The communication control unit of the vehicle-installed device sets the timing of transmitting a response signal for the received interrogation signal to a time point at which time at least a predetermined length of time elapses, the time point being within the interrogation signal transmission cycle.

As a result, for example, if a plurality of small

vehicles travel side-by-side and enter the communication overlapping area and start communications with neighboring antenna units, the response signals from the vehicle-installed devices will not conflict with each other since the communication control unit of the vehicle-installed device delays the response signal transmission timing. If the response signal were transmitted immediately when the signal is generated without the timing delay operation, the response signal could interfere with the response signal from the other vehicle-installed device. Thus, the vehicle communication system according to this aspect of the invention substantially prevents radio interference and performs communications without a failure.

Preferably, the communication control unit includes a timer that starts simultaneously with reception of the interrogation signal to count transmission inhibition time, and the communication control unit transmits the interrogation signal if the time counting operation of the timer has ended.

According to this aspect of the invention, the communication control unit starts the timer counting operation of the timer when receiving an interrogation signal, and transmits a response signal for the interrogation signal if the time counting operation of the timer has ended and the transmission inhibition time has elapsed. As a result, if a plurality of small vehicles travel side-by-side and enter the communication overlapping area and start communications with neighboring antenna units, the response signals will not conflict with each other as described above. Thus, the vehicle

communication system according to this aspect of the invention substantially prevents radio interference and performs communications without a failure.

Another aspect of the present invention provides a plurality of antenna units provided corresponding to a plurality of communication areas for performing communications by transmitting interrogation signals in a predetermined cycle and for receiving a response signal from the communication areas; a vehicle-installed device for setting different timings of transmitting interrogation signals for at least those of the plurality of antenna units whose communication areas neighbor and overlap each other so that the timings are shifted from each other by half of the transmission cycle, and for identifying a vehicle passing through one of the communication areas on the basis of a signal received; a vehicle-installed device provided in a vehicle for transmitting a response signal when receiving an interrogation signal from one of the antenna units and for, when receiving an interrogation signal again from the same antenna unit, transmitting an interrogation response signal, to perform communications; and a communication control unit provided in the antenna units for adjusting transmission of the interrogation signal so that the expected timing of transmitting the response signal for that interrogation signal will be a time point at which time at least a predetermined length of time elapses, the time point being within the transmission cycle of the interrogation signal.

According to this aspect of the invention, for

transmission of an interrogation signal, the antenna unit uses the communication control unit to adjust transmission of the interrogation signal so that the expected timing of transmitting the response signal for that interrogation signal will be a time point at which time at least a predetermined length of time elapses, the time point being within the transmission cycle of the interrogation signal.

As a result, if a plurality of small vehicles travel side-by-side and enter the communication overlapping area and start communications with neighboring antenna units, the response signals will not conflict with each other as described above. Thus, the vehicle communication system according to this aspect of the invention substantially prevents radio interference and performs communications without a failure.

If the communication control unit delays the timing of transmitting the interrogation signal, the communication control unit may transmit a dummy signal until the interrogation signal is transmitted. As a result, if a plurality of small vehicles travel side by side and enter the communication overlapping area and start communications with neighboring antenna units, the response signals will not conflict with each other as described above. Thus, the vehicle communication system according to this aspect of the invention substantially prevents radio interference and performs communications without a failure.

Other objects and features of the invention will appear in the course of the description thereof, which follows.

BRIEF DESCRIPTION OF THE DRAWINGS

Additional objects and advantages of the present invention will be more readily apparent from the following detailed description of preferred embodiments thereof when taken together with the accompanying drawings in which:

FIG. 1 is a block diagram of a first preferred embodiment of the invention;

FIG. 2 is an exterior perspective view of the overall construction of the first embodiment;

FIG. 3 is a vertical sectional view of a road-installed device according to the first embodiment;

FIG. 4 indicates the frequencies assigned to the antenna elements and the reception frequency characteristics of a vehicle-installed device in the first embodiment;

FIG. 5 illustrates positional relationships when a plurality of vehicle-installed devices pass through the overlapping area;

FIG. 6 is a flowchart of the main program illustrating the control operation performed by the vehicle-installed device when receiving a signal;

FIG. 7 is a flowchart of the reception interruption program;

FIG. 8 is a flowchart of the timer interruption program.

FIG. 9 is a timing chart illustrating various assigned times within the communication cycle;

FIG. 10 is a timing chart illustrating the timings of

transmitting an interrogation signal and a response signal within the communication cycle;

FIG. 11 is a timing chart illustrating the timings of transmitting an interrogation signal and a response signal within the communication cycle;

FIGS. 12A - 12D are timing charts illustrating the status of communications between the antenna units and the vehicle-installed devices;

FIG. 13 is a timing chart illustrating the operation of a second preferred embodiment of the present invention, corresponding to FIGS. 12A - 12D;

FIG. 14 is a timing chart illustrating the operation of a third preferred embodiment of the present invention, corresponding to FIG. 12A - 12D;

FIG. 15 illustrates the drawbacks of the conventional art, corresponding to FIG. 5; and

FIGS. 16A - 16D are timing charts illustrating timing problems in the prior art, corresponding to FIGS. 12A - 12D.

DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EXEMPLARY EMBODIMENTS

The preferred embodiments of the present invention are hereinafter described with reference to the accompanying drawings.

A first embodiment in which the present invention is applied to a toll charging system for an express highway will be described hereinafter with reference to FIGS. 1 to 12D.

Referring first to FIG. 2 which illustrates an overall view of the system, a toll express road 11 (only lanes having one direction of travel are shown) has three lanes 12, 13, 1. predetermined toll charging point is provided with a gantry 15 extending over the road 11. The gantry 15 serves as a road-installed device. The gantry 15 has antenna units 16 - 18 directed downward corresponding to the respective lanes 12 - 14 to determine communication areas 19 - 21.

The communication areas 19 - 21 are set in such a direction from the respective antenna units 16 - 18 that they cover approaching traffic (represented by motor vehicles 29). According to this embodiment, the antenna unit 16 has antenna elements 22a, 22b that determine communicative areas 19a, 19b, respectively, that together provide the communication area 19 as a result. Similarly, the antenna unit 17 has antenna elements 23a, 23b that determine communicative areas 20a, 20b, respectively, that together provide the communication area 20 as a result. The antenna unit 18 has antenna elements 24a, 24b that determine communicative areas 21a, 21b, respectively, that together provide the communication area 21 as a result.

As shown in FIG. 3, each of the antenna units 16 - 18 has a water-tight construction comprising (using antenna unit 16 as an example) a base 25 connected to the lower surface of the gantry 15, the antenna elements 22a, 22b and a control circuit section 26 mounted on the base 25, and a plastic cover 27 that is permeable to radio waves. The control circuit section 26 includes an electrical construction as described below that

control the driving of the antenna elements 22a, 22b for transmitting and receiving operations. The antenna elements 22a, 22b are rotatably supported by support shafts 28 so that the orientation of the radiation surface of each antenna element 22a, 22b can be adjusted. Although not shown in the figures, each antenna element is also rotatably supported with respect to a direction perpendicular to the support shaft 28 by a well-known structure so that the orientation of the radiation surface can also be adjusted with respect to directions perpendicular to the support shaft 28.

The communicative areas 19a, 19b depend on the angles of the radiation surfaces of the antenna elements 22a, 22b, respectively, that together provide the communication area 19 as a result, as described above. The two communicative areas are defined to form an overlapping area 19c. Thus, the communicative areas 19a, 19b are contiguous and leave no space therebetween (similarly, the other antenna elements 23a, 23b, 24a, 24b produce overlapping areas 20c, 21c). The antenna elements 22a, 22b output microwaves at frequencies different from each other for communication with vehicle-installed devices.

Each of the antenna elements 22a, 22b, 23a, 23b, 24a and 24b is a micro-strip type array antenna element produced by forming eight patches of a generally square shape on one of the side surfaces of a printed circuit board and connecting the patches by transmission lines to the feeding terminal. The printed circuit board used is formed of a resin material and printed on both sides (i.e., it is a two-side printed circuit

board). The resin material used has a dielectric constant having such a temperature expansion characteristic that the variation within the operating temperature range (for example, with the upper limit being about 120°C) is a predetermined level or lower (for example, 1% or lower). For example, a BT resin material or a glass epoxy material has been used.

Although a typical array antenna comprising many patches exhibits side lobes, the antenna elements 22a, 22b reduce side lobes by adjusting the impedance of the transmission lines to prevent communication impossibility areas from occurring in the communication area. For example, each of the antenna elements 22a, 22b is designed to cover substantially the same area within a height range of about 1 to 2 meters; that is, the height range through which the vehicle-installed device 30 passes.

The motor vehicles 29 traveling on the express road 11 have devices 30 (shown in FIG. 2) installed close to their dash boards. Each vehicle-installed device 30 has an antenna 31 for receiving pilot signals and interrogation signals from the antenna units 16 - 18 as shown in FIG. 1. The antenna 31 is also a micro-strip type antenna comprising two patches of a generally square shape formed on a printed circuit board as used for the antenna element 22a. The two patches are separate patches provided for transmission and reception.

The antenna 31 reflects an unmodulated carrier wave from the antenna unit 16 while modulating the carrier wave with a response signal for transmission of a response signal. That

is, the vehicle-installed device 30 transmits a response signal by receiving an unmodulated carrier wave from the antenna units 16 - 18 within the communication areas 19 - 21 and by reflecting it as a response signal while receiving it.

The electrical structure of the system will now be described with reference to FIG. 1. First, the similarly constructed antenna units 16 - 18 will be described by referring to the antenna unit 16 shown in FIG. 1. A control section 33 for controlling control circuits 32a, 32b provided respectively for the antenna elements 22a, 22b includes a control circuit 34, a power source circuit 35, and interface circuit 36 for exchanging data with an external device.

In each of the control circuits 32a, 32b provided for the antenna elements 22a, 22b, a modulating circuit 37 modulates a carrier wave, that is, an oscillation output from an oscillator 38 of a predetermined frequency, with an interrogation signal or a pilot interrogation signal provided by the control circuit 34, and outputs it to the antenna element 22a via a circulator 39.

A reception circuit 40 for signal processings, such as demodulation, is connected to a mixer 41. The mixer 41 receives an oscillation output from the oscillator 38 and also receives from the antenna element 22a a radio wave signal corresponding to a response signal. The carrier wave and the radio wave signal corresponding to the response signal are mixed by the mixer 41 and then outputted to the reception circuit 40. The reception circuit 40 demodulates the composite signal into a response signal and outputs the signal to the control circuit 34.

Each of the oscillators 38 provided respectively for the antenna elements 22a - 24b outputs the carrier wave in the form of quasi-microwaves within a predetermined frequency range assigned thereto, for example, in the 2.45 GHz band. As indicated in FIG. 4, each oscillator 38 is assigned with one of the frequencies f1 to f6 that are different narrow frequency ranges within the aforementioned frequency band and output the assigned frequency. On the other hand, the vehicle-installed device 30 is designed to receive all the signals corresponding to the oscillating frequencies f1 - f6 of the oscillators 38, as described later.

The thus-constructed antenna units 16 - 18 receive timing signals driven corresponding to the respective antenna elements 22a - 24b by a control device (not shown) connected thereto by the interface circuit 36. The timing signals are determined such that the neighboring antenna units 16, 17 and 17, 18 output pilot interrogation signals and interrogation signals at timings that are shifted half an interrogation timing cycle from each other. Thereby, if the vehicle-installed device 30 of a motor vehicle passes through, for example, an area where the communication areas 19, 20 overlap, the vehicle-installed device 30 will not simultaneously receives pilot signals from two antenna units 16, 17.

In the vehicle-installed device 30, a control circuit 42 constituting the communication control unit includes a ROM and a RAM. According to a pre-stored program, the control circuit 42 outputs various data, such as the vehicle's identification

code, in response to a pilot signal or an interrogation signal. The control circuit 42 is connected to the antenna 31 via a transmission circuit 43, and also via a reception circuit 44.

The transmission circuit 43 performs modulation in accordance with a response signal to modulate the unmodulated carrier wave received by the antenna 31 in order to perform transmission, and the reception circuit 44 demodulates the radio wave received by the antenna 31 into an interrogation signal and supplies the signal to the control circuit 42, thus forming a semi-double construction. The control circuit 42 is connected to a data memory 45, that is, a read/write non-volatile memory. A battery 46 supplies power to the circuits provided in the vehicle-installed device 30.

Although not shown in the Figures, the control circuit 42 is provided with a starting circuit that starts the entire device to switch from "sleep status" to "wake-up status" to operate for communications and, when the communications end, switches the entire device to the "sleep status" to stand ready for reception of a signal from the outside. This construction minimizes the load on the battery 46 when communications are not performed.

The operation of this embodiment will be described with reference to FIGS. 5 - 13. In a normal case where it is assumed that motor vehicles travel separately in lanes 12 - 14, the antenna units 16 - 18 perform communications with the vehicle-installed devices 30 of the motor vehicles traveling through their respective communication areas 19 - 21 to exchange tolling

data without failure similar to the conventional art. When the starting circuit switches the vehicle-installed device 30 to "wake-up status", that is, the device is started, the control circuit 42 executes the program illustrated by the flowchart of FIG. 7 for communications.

In normal operation for communications, the vehicle-installed device 30 operates as described below when entering one of the communication areas 19 - 21 and receives a pilot signal PLT. First, the control circuit 42 is started to start the program. The control circuit 42 determines whether reception interruption has occurred (step S1). According to this embodiment, the reception interruption occurs when a pilot signal is received and the control circuit 42 becomes started. If the negative determination is made in this step, reception interruption will occur. The control circuit 42 then holds the processing in this step until the reception interruption ends.

Then, since the control circuit 42 has received a pilot signal PLT, the control circuit 42 executes the reception interruption program as illustrated in FIG. 7. The control circuit 42 first checks the data of the received pilot signal PLT to determine whether the signal carries any abnormal data (step T1). If there is any abnormal data, which means that the received pilot signal is not correct, negative determination is made in step T1 and the control circuits ends the program and returns to the main program. If there is no abnormal data, affirmative determination is made and the operation proceeds to step T2.

The control circuit 42 determines a response waiting time based on the content of the received signal (step T2), and sets the response waiting time in the interruption timer circuit 47 and starts the circuit 47 (step T3), and performs post-interruption processing (step T4), and then returns to the main program. The timer circuit 47 thus starts to count the timer time, which is a transmission inhibition time. When the time set in the timer circuit 47 elapses, the timer circuit 47 outputs a timer interruption signal to the control circuit 42.

The timer circuit 47 is set to, for example, 4 ms, as the timer time, that is, the transmission inhibition time. Thus, transmission of a response signal is held for 4 ms following reception of a signal from the outside.

When returning to the main program, the control circuit 42 analyzes the content of the received signal and executes the content (step S2), and then generates a response signal based on the result of processing (step S3). The control circuit 42 generates a response signal at this stage and waits for the timing of transmitting the signal. The control circuit 42 then assumes a state for permitting timer interruption in response to the interruption signal from the timer circuit 47 (step S4). Then, the control circuit 42 waits for a timer interruption to transmit the response signal (step S5).

If the interruption signal from the timer circuit 47 has been inputted to the control circuit 42 in step 5, or if the interruption signal from the timer circuit 47 is inputted while step S5 is repeated, the control circuit 42 executes the timer

interruption program as illustrated in FIG. 8. The control circuit 42 starts transmitting the response signal (step P1), and performs the post-interruption processing (step P2), and returns to the main routine. After completing transmitting the response signal by this processing, the control circuit 42 makes an affirmative determination in step S5 of the main program and returns to step S1.

The control circuit 42 of the vehicle-installed device 30 generates and transmits a response signal every time it receives a signal from the outside, as described above and shown in FIG. 9. In the normal state, when receiving a pilot signal PLT from any of the antenna units 16 - 18, the control circuit 42 performs the communication processing as described below while repeatedly performing the above-described processing.

When the control circuit 42 receives a pilot signal PLT1 from, for example, the antenna unit 16, the control circuit 42 determines the antenna unit that has transmitted the pilot signal PLT as a fixed communication party for the later communications, and set up a status to reject pilot signals PLT from the other antenna units if any are received. In this status, the control circuit 42 generates a pilot response signal in response to the pilot signal PLT, and reflects the unmodulated carrier wave continually transmitted from the antenna unit by modulating it with the generated pilot response signal RSP, thus transmitting the pilot response signal RSP. The pilot response signal RSP carries an identification code that has been registered as a code specific to the vehicle-installed device 30.

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After that, the antenna unit 16 transmits a vehicle-installed-device data request signal RC1 as an interrogation signal following the pilot signal PLT. The vehicle-installed-device data request signal RC1 carries a code indicating the location, the code number of the gantry, and the identification code registered corresponding to the vehicle-installed device 30, thereby causing only the vehicle-installed device 30 to perform a communication operation following the reception of the signal.

When receiving the vehicle-installed-device data request signal RC1, the vehicle-installed device 30 reads out data, such as data on account balance, to generate a card read signal RD1, and then transmits the signal to the antenna unit 16 in the manner as described above. When the antenna unit 16 receives the read signal RD1, the antenna unit 16 transmits to the vehicle-installed device 30 predetermined data required for tolling data processing as a write signal WD1. The write signal WD1 carriers a toll instruction code, toll amount data, a location code number, the gantry code number, the identification code of the vehicle-installed device 30, operation time data, etc. If the response signal RS1 from the vehicle-installed device 30 is abnormal, the antenna unit 16 execute a predetermined abnormality processing routine.

When the vehicle-installed device 30 receives the write signal WD1, the vehicle-installed device 30 performs predetermined writing processing. The vehicle-installed device 30 then transmits a write end signal END1 carrying a location

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of the vehicle-installed device 30 in the manner as described above. Upon receiving the write end signal END 1, the antenna unit 16 transmits an end acknowledge signal ACK1 to the vehicle-installed device 30 to inform it of reception of the write end signal END1. Upon receiving the end acknowledge signal ACK1, the vehicle-installed device 30 determines that communications have been completed. The starting circuit stops to switch the device 30 to "sleep status", that is, the same status before the starting of communications.

If the vehicle-installed device 30 receives a pilot interrogation signal again in the communication areas 19 - 21 of the road-installed device 15 after it has completed communication processing, the vehicle-installed device 30 ignores the signal with reference to the data on communication results stored, thereby avoiding interfering with the communications by other vehicle-installed devices. This function prevents the vehicle-installed device 30 from repeating communications within the same communication area 19 or the communication areas of the same gantry 15, thus eliminating the possibility of double charging of a toll.

For actual toll processing, the vehicle-installed device 30 is designed to accommodate an IC card. After passing through the communication area 16, the vehicle-installed device 30 writes in the IC card through an IC card interface the data corresponding to the amount obtained by subtracting the toll amount data transmitted during the communications from the balance on the basis of various data specified by the write

signal WD1.

Assurance of reliable communication processing will be described with reference to the case where a communication impossibility state may occur as described in the Description of the Related Art. Let it be assumed that the small vehicles, such as motorcycles, are traveling side-by-side and the vehicle-installed devices 30a, 30b installed therein substantially simultaneously enter and pass through the overlapping area D. More specifically, it is assumed that communications have been started by the vehicle-installed device 30a receiving the pilot signal PLT1 from the antenna unit 16 and the vehicle-installed device 30b receiving the pilot signal PLT2 from the antenna unit 17.

For the communications between the vehicle-installed devices 30a, 30b and the antenna units 17, 16, the following times are set. The communication cycle is set to, for example, 10 ms. The communication cycles of the antenna unit 16, 17 are shifted from each other by 5 ms. The interrogation signal-assigned time TQ for, for example, pilot signals PLT and interrogation signals RC, is set to a time within the range from the start time of the cycle and the maximum 5 ms. On the other hand, the response signal-assigned time TA, that is, the timing of transmitting response signals from the vehicle-installed devices 30a, 30b, is set to 5 ms from 4 to 9 ms. The processing time TC of the antenna units 16, 17 for processing the received response signals is allocated to the last 1 ms of the cycle, that

The manner of setting the response waiting time TQ will be described.

First of all, the vehicle-installed device 30b (30a) must transmit an interrogation signal after the antenna unit 16 (17) has started processing the response signal received. This is because before the antenna unit 17 (16) starts processing the received response signal, there is a possibility that the vehicle-installed device 30a (30b) may still be transmitting a response signal. Therefore, the response waiting time TQ is set to a time period from the timing of transmission of an interrogation signal from the antenna unit 17 (16) until the start of the processing of the response signal by the antenna unit 16 (17).

The waiting time TQ, that is, the time period from the timing of transmission of an interrogation signal from the antenna unit 17 (16) until the start of the processing of the response signal by the antenna unit 16 (17) is provided by the following equation:

$$TQ = T\ (1 - X - C)$$

where TX is a shift between the timings of transmission of the response signals from the antenna units 16 and 17, and TC is a time required for processing the response signal received.

Among the aforementioned time periods, the response signal-assigned time TA is set at the vehicle-installed devices 30a, 30b. During that time, a start trigger is outputted to the timer circuit 47 to start the timer operation when a pilot signal or an interrogation signal is received, and the response signal

is transmitted when a timer interruption signal is inputted when the response waiting time elapses.

Where the two vehicle-installed devices 30a, 30b located in the overlapping area D perform communications with the antenna units 16, 17, the response signals transmitted at transmission timings from the two devices may overlap each other depending on the transmission timings. If the overlapping of the response signals occurs in the overlapping area D, each of the antenna units 16, 17 receives the responses signals from the two devices, thus causing interference. This embodiment avoids this event by the timer circuit 47 setting a response waiting time.

In the case illustrated in FIG. 10, as for example, where an interrogation signal lasts for 3 ms and the processing time TS required for the interrogation signal is 1 ms, the transmission timing of the response signal will be between 4 ms and 9 ms. In the case illustrated in FIG. 11, where an interrogation signal lasts for 5 ms and the processing time TS required for the interrogation signal is 2 ms, the transmission timing for the response signal will be between 7 ms and 9 ms.

Since, as shown in FIGS. 12A - 12D, this embodiment has a construction where the timer circuit 47 is provided in the vehicle-installed device 30 for controlling the response signal transmission timing to a timing later than the elapsing of a predetermined length of time, and where the control circuit 42 transmits a response signal after receiving a timer interruption signal from the timer circuit 27, the embodiment substantially prevents communication interference by preventing the overlapping

of response signals even in the case where a plurality of small vehicles, such as motorcycles, travel side-by-side and the vehicle-installed devices 30a, 30b of the vehicles perform communications with the antenna units 16, 17 while passing through the overlapping area D. Thus, the embodiment performs communication processing and the tolling operation without a failure.

Also, according to this embodiment, between adjacent antenna units 16, 17 and antenna units 17, 18, the output timing of the pilot query signal and the query signal to the communication area is shifted a half-cycle from the repetition cycle (10 ms), the output timing of the pilot query signal and the query signal to the communication areas 19, 21 are the same for the antenna units 16, 18, with the query signal allotted time TQ, response time allotted time TA and the response signal processing time TC all having the same timing. Therefore, even if the frequencies of the pilot query and the query signals generated from the antenna units 16, 18 are made to be equal, the signal generated from the antenna unit 16 will no longer interfere with the antenna unit 18 nor will the signal generated from the antenna unit 18 interfere with antenna unit 16.

In other words, for a plurality of neighboring antenna units, there are cases when interference occurs if an antenna unit which is receiving a signal from the vehicle-mounted unit receives a signal generated from the other antenna units. To prevent this interference, it might be good to make the frequency

antenna unit. However, normally, because the frequency region for transmission is usually set beforehand (2.45 GHz band), if there are a plurality of antenna units (N) and (N) channels of different frequencies are allotted for the antenna units, the bandwidth for each antenna unit becomes N/2.45 Ghz, and thus, the bandwidth becomes narrower as it is limited by the number of antenna units. If the bandwidth is limited and becomes narrow, there is the problem of having difficulty in raising the communication baud rate between the vehicle-mounted units and the antenna units.

To solve this problem, one method of preventing interference between a plurality of adjacent antenna units is to time share the interval when the antenna units perform communication. However while the communication baud rate can be accelerated with this method, the communicable time for each antenna unit is limited by the time divisions and so, there is the problem of not being able to secure enough communication time.

In the above embodiment, because the query signal allotted time TQ, response time allotted time TA and the response signal processing time TC timing are made to be the same for antenna units that are two antenna units away from each other, between neighboring antenna units 16, 18, antenna unit 16 (or 18) will not generate a signal when antenna unit 18 (or 16) is receiving a signal. In other words, in the above embodiment, because there will no longer be mutual interference even if the

generated from the antenna units 16, 18, are the same, then the frequencies of only adjacent units need be changed to prevent interference between neighboring units. In other words, two channels of communication frequency would suffice to prevent interference between antenna units.

Also, because the communication timing for antenna units 16, 18 are the same, the communicable time per antenna unit can be fully extended.

It must be noted here that to make the frequencies of the pilot query signal and the query signal equal, there is a need to raise the frequency accuracy using PLLs or the like. Also, when there are a number of antenna units, the disparity due to antenna units having the same frequency channel cannot be completely eliminated and so if there is a need to provide some distance between antenna units, the frequencies for communication can be set to 4 channels.

FIG. 13 illustrates a second embodiment of the invention. The features distinguishing the second embodiment from the first embodiment will be described. According to the second embodiment, a timer function is provided in antenna units 16 - 18, instead of providing the timer circuit 47 in a vehicle-installed device 30. If it is expected that the vehicle-installed device 30 will transmit a response signal at timing earlier than 4 ms in response to a pilot signal or an interrogation signal from any of the antenna units 16 - 18, a control circuit 34 provided as the communication control unit

or interrogation signal as a preamble of the signal so that the response signal transmission timing of the vehicle-installed device 30 will be 4 ms or later as indicated in FIG. 13.

This embodiment eliminates the need for providing measures for interference in many vehicle-installed devices 30 by providing the control circuit 34 of the antenna units 16-18 with the function of adding a preamble to a pilot signal or an interrogation signal if necessary. The second embodiment thus prevents communication interference even in the case described in conjunction with the first embodiment.

FIG. 14 illustrates a third embodiment of the invention. The third embodiment is distinguished from the second embodiment by a construction where a control circuit 34 of each of antenna units 16-18 does not add a preamble to an interrogation signal or interrogation signal but sets a delay time Td corresponding to the time of the preamble to accordingly delay transmission. The third embodiment achieves substantially the same advantages as achieved by the second embodiment.

Although the present invention has been fully described in connection with the preferred embodiment thereof with reference to the accompanying drawings, it is to be noted that various changes and modifications will become apparent to those skilled in the art. Such changes and modifications are to be understood as being included within the scope of the present invention as defined by the appended claims. Examples of such changes and modifications follow.

circuit 42 may be provided with a software timer function by programming. In this construction, however, while the CPU performs the timer function, the CPU cannot perform other processing. Therefore, the timer time must be counted while taking into the consideration the time required for processing interrogation signals or the like.

As for the dummy signal added as a preamble of a pilot signal or an interrogation signal, the dummy signal may be a mere time adjusting signal irrelevant to the content of communications or a signal carrying data needed for communications.

Besides toll collection for express roads, the invention can also be applied to parking fee collection for auto parks. This application will allow an entrance/exit design with a plurality of gates such that a plurality of vehicles can simultaneously enter and eliminates the need to stop each vehicle at the entrance and/or exit to perform fee collecting operations, thus enabling speedy entrance to and exit from the auto park and reducing man power requirements.

In addition to tolling operations, the invention may be applied to various forms of data exchanging such as research on traffic. For example, the invention may be used for research on traffic volume for the purpose of preparation of traffic information, city traffic planning and the like. The invention can be applied not only to a road of three lanes, but also to roads of two lanes or more than three lanes.

The vehicle-installed device may be left in operation

on reception of a pilot interrogation signal.

The vehicle-installed device may be left in operation all the time, instead of incorporating the function of waking up on reception of a pilot interrogation signal. Also, the antenna elements may employ structures other than the above-described patch structure. Further, the vehicle-installed device may be equipped with an oscillator for transmitting response signals, rather than the passive reflective modulation arrangement described above.

Whereas the vehicle-installed device determines the antenna unit 16 as a fixed communication party immediately when receiving a pilot signal from the antenna unit 16 according to the above-described embodiments, the following construction may also be employed. That is, after receiving a pilot signal from the antenna unit 16, the vehicle-installed device ignores pilot signals received from other antenna units for the period of communication cycle T. Then, upon receiving an interrogation signal, the vehicle-installed device determines the antenna unit 16 as a fixed communication party.

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WHAT IS CLAIMED IS:

1. A vehicle communication system comprising:

a plurality of antenna units provided at a plurality of corresponding communication areas for performing communication by transmitting interrogation signals according to a predetermined cycle T and receiving response signals from said communication areas;

a vehicle-mounted unit mounted on a vehicle which, after receiving a interrogation signal from a given one of said plurality of antenna units, performs communications by sending a response signal to said given antenna unit;

setting means for setting a transmission timing of interrogation signals from at least antenna units whose communication areas overlap with adjacent communication areas to a timing in which a transmission cycle T of those interrogation signals is shifted by a timing TX ($0 < X < 1$) relative to timings of antenna units corresponding to said adjacent communication areas;

identification means for identifying said vehicle when said vehicle passes through said communication area by processing said response signal from said vehicle within a predetermined interval TC ($0 < C < 1$, $C + X < 1$) in said communication cycle T; and

communication control means for setting a transmission timing of said response signal from said vehicle-mounted unit to an interval from T(1-X-C) to T(1-C) after receipt of said

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2. A vehicle communication system according to claim 1, wherein said communication control means is disposed in said vehicle-mounted unit.

3. A vehicle communication system according to claim 2, wherein:

said communication control means includes a timer that starts simultaneously with receipt of interrogation signals to count a transmission prohibition time; and

said communication control means is further for transmitting said response signal contingent upon said timer completing timing of said transmission prohibition time.

4. A vehicle communication system according to claim 1, wherein said communication control means is disposed in said setting means.

5. A vehicle communication system according to claim 4, wherein said communication control means is further for transmitting a dummy signal until a interrogation signal is transmitted when said communication control means delays said timing of transmitting said interrogation signals.

6. A method for performing communications between a plurality of antenna units and a vehicle-mounted unit in a

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using a plurality of antenna units at a plurality of corresponding communication areas, transmitting interrogation signals according to a predetermined cycle T and receiving response signals from said communication areas;

using a vehicle-mounted unit mounted on a vehicle, sending a response signal to a given one of said plurality of antenna units after receiving a interrogation signal from said given antenna unit;

setting a transmission timing of interrogation signals from at least antenna units whose communication areas overlap with adjacent communication areas to a timing in which a transmission cycle T of those interrogation signals is shifted by a timing TX ($0 < X < 1$) relative to timings of antenna units corresponding to said adjacent communication areas;

identifying said vehicle when said vehicle passes through said communication area by processing said response signal from said vehicle within a predetermined interval TC ($0 < C < 1$, $C + X < 1$) in said communication cycle T; and

setting a transmission timing of said response signal from said vehicle-mounted unit to an interval from T(1-X-C) to T(1-C) after receipt of said response signal.

7. A method according to claim 6, said response signal transmitting timing setting step comprising the steps of:

receiving a interrogation signal;

executing said received interrogation signal;

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interrogation signal;

initiating an interrupt timer; and

waiting for an interrupt from said timer before receiving a subsequent interrogation signal.

8. A method according to claim 7, said executing step comprising the steps of:

checking said interrogation signal for errors;

if said interrogation signal is error-free,

determining a response time based on information in said interrogation signal; and

setting said response time in said interrupt timer.

9. A method according to claim 7, further comprising a step of, when said response signal is generated before said interrupt from said interrupt timer, transmitting said response signal responsive to said interrupt from said interrupt timer.

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