# The Development of Free-Flow ETC System and the Future


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*The newly developed free-flow electronic toll collection (ETC) system is a toll collection system aimed at solving such problems of city expressways as: (1) easing of traffic congestion at the center of the city, (2) improvement of environment along the expressways, (3) procurement of land (site) for new toll plaza and (4) diversification of toll system. The system has started joint operation as an ETC system for transit vehicles at Hanshin Expressway Public Corporation since July 2002, and is expected to be used successively as an ETC system for special zone toll collection by the end of fiscal year 2002, and as the ETC system for transit vehicles via ETC of Kobe Municipal Expressways Public Corporation. The system easily applicable to the road pricing system can be used as an unmanned system not only in city expressways, but also in other public corporations for roads and expressways.*


## 1. Introduction

The free-flow ETC system is a system of collecting tolls without requiring the passing vehicles to stop at the toll collecting plazas. The system is similar to the electronic road pricing (ERP) system operating in Singapore since 1998.

The new free-flow ETC system has been developed for Hanshin Expressway Public Corporation as an ETC system for transit vehicles. The ETC transit is a system that treats the unlinked different roads as if they were a continuous road, allowing only the ETC vehicles passing through the specified transit zone during specified time to pass.

The Hanshin Expressway Public Corporation has been adopting a manned system of exempting toll collection from vehicles running through the designated transit routes by requiring the driver to take the transit ticket at the transit exit gate and to submit it at the transit entrance gate.

In July 2002 the ETC system was introduced in all entrance toll plazas and the free-flow ETC system was installed at 4 transit exit gates between Kobe Route No. 3 and Wangan (Gulf) Route No. 5 (Kyobashi, Maya, Rokko Island Kita and Sumiyoshihama). **Fig. 1** shows the schematic diagram of the route. Unlike the ETC system installed at toll plazas (hereafter "conventional ETC system"), the new system has been developed for toll plazas with no reserve (median) called island for each lane or for the lane where the installation of the conventional ETC system is difficult.

## 2. Outline of free-flow ETC system

The free-flow ETC system, differing largely from the conventional ETC system in equipment configuration, is composed of the portal gantry (hereafter "gantry") installed on the off ramp or over the main lane. This exempts driver from slowing down or making a stop as he or she approaches the existing toll plaza using the conventional ETC system, and enables to read or write the passage data (passage history, utility details, etc.) through communication between the onboard unit (equipment) and the road side equipment as the vehicle passes under the gantry.

## 3. Urban expressway system and future problems

Below is the brief description how the newly developed free-flow ETC system deals with the problems of urban expressway given below.

(1) Easing of traffic congestion at the center of the city
(2) improvement of environment along the expressways
(3) procurement of land (site) for new toll plaza
(4) Diversification of toll system

Compared with the conventional ETC system, the free-flow ETC system has been developed for vehicles running freely at high speed. However, the traffic congestion even in the same lane of an urban (city) expressway depends also on the day and time zone. Widening the lane and increasing the number of toll plazas are suggested as the solution to such problems, but the flow of traffic volume can be dispersed by introducing the road pricing system, etc.

In order to restrict the number of cars (traffic volume) passing through residential areas, environmental road pricing is already carried out in some routes (between Kobe Route No. 3 and Wangan Route No. 5) of Hanshin Expressway Public Corporation. In order to adjust the traffic volume strictly, however, appropriate installation (introduction) of the free-flow ETC system is effective, as the system can be applied not only to the transit to the other routes, but also to the diversified toll systems such as road pricing (passage discount, time-wise discount, etc.) and toll collection at special zones.

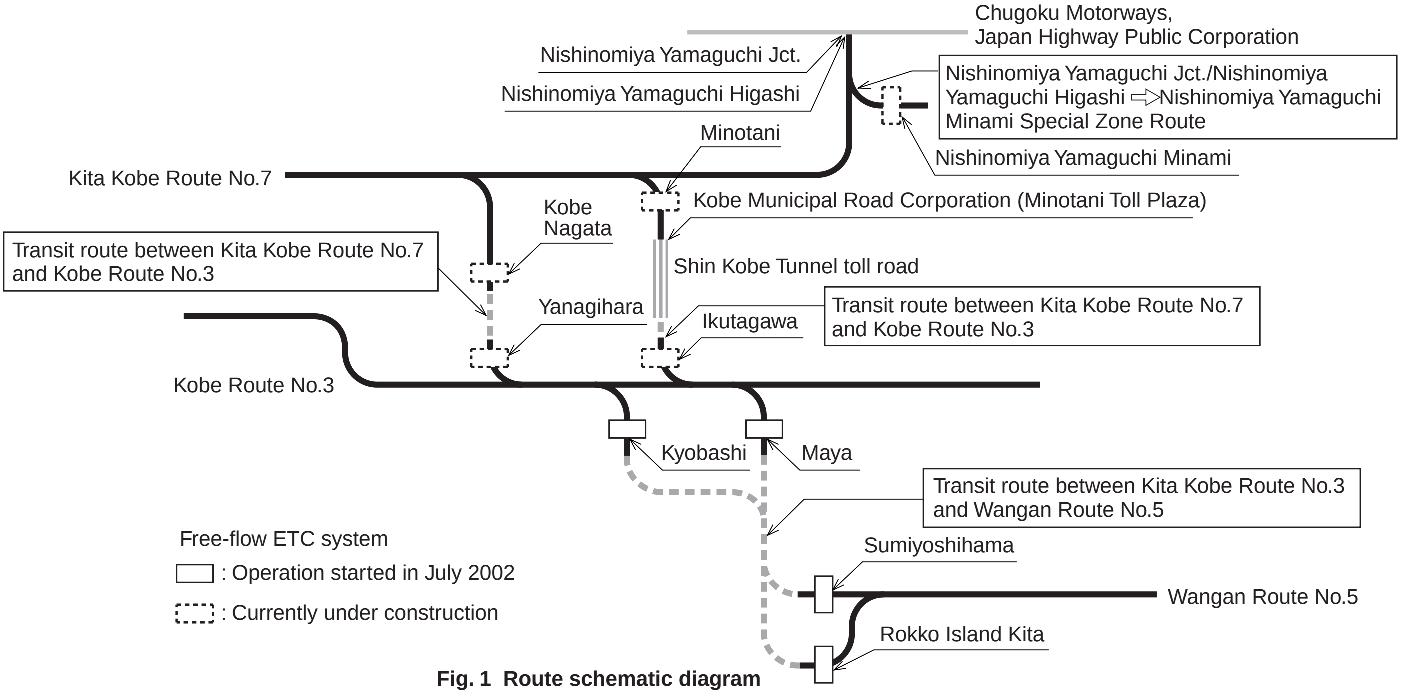



**Fig. 1 Route schematic diagram**

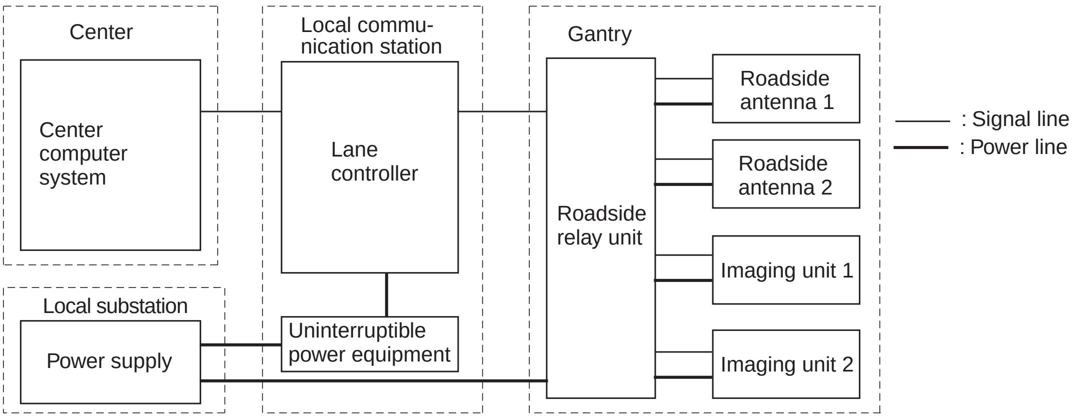



**Fig. 2 System configuration**

### 3.1 Points of difference between free-flow ETC system and conventional ETC system

As mentioned above, the newly developed systems are installed in all 4 exits on two-lane off ramps. This allows the vehicles to run freely on different lanes (cruising lane/overtaking lane), needing a system different from the conventional ETC system where vehicles entering each lane are subjected one by one to sequential transaction.

### 3.2 Features of urban expressway system

The peripheral roads run adjacent to one another or are under the elevated roads as the special features of the urban expressways. This, however, should not obstruct the communication due to the leakage of radio waves outside the roads, and calls for a communication system capable of distinguishing without fail the vehicles running in parallel/diagonal or running fast/slow (as in traffic congestion).

Unlike the conventional ETC system where the system can be brought to stop for maintenance or due to some trouble simply by closing the concerned lane only, the free-flow ETC system lanes cover the full width of the off ramp, so that "closing of lanes" = "closing the traffic." Therefore, a double system has to be adopted, so that when one system is out of use for maintenance or due to some trouble, the other system can be operated.

Further, the system must have a remote monitoring system installed to the center computer system to monitor the operating status of the system and to carry out remote control (for start and stop of operation) to allow round-the-clock unmanned operation.

In order to solve the aforesaid problems, the following items were taken as the system requirements at the time of development.

## 4. System specifications

The system configuration of the newly developed system is shown in **Fig. 2**, with the camera unit being an optional function.

### 4.1 System requirements

(1) Non-stop round-the-clock unmanned operation and remote operation (start and stop) from center computer system must be possible.

(2) All roadside equipment can be installed on the gantry.
(3) The system must be capable of simultaneous radio communication with multiple vehicles running freely along the full width of the road. Further, the system must be able to recognize the license plate number as an optional function.
(4) The radio frequency (RF) communication must be 2-antenna type to enable communication over the road width ranging from 5.5 m (single lane + shoulder zone) to 7.0 m (2 lanes). Further, the radio frequency communication unit must cover the communication of 2 lanes using one antenna in case the other one gets out of order.
(5) The roadside antenna must suppress the radio wave from leaking out of the road, preferably needing no wall for radio wave absorption.
(6) The lane controller must be installed more than several kilometers away from the roadside equipment.
(7) The lane controller must be able to continue operation using the roadside system even if some circuit trouble (error) occurs in the center computer system. It must be capable of storing the detailed utility data to transmit automatically to the center computer system after the circuit returns to normal state.

**4.2 System specifications**

(1) The roadside RF unit will have the roadside antenna constantly activated.
(2) The communication slot will be of full-duplex 4-slot configuration.
(3) The roadside antenna will be installed as per roadside RF unit, with the 2-antenna, frequency-division multiple-access control adopted for RF communication.
The communication range will cover 4.5 m in the moving direction of the vehicle, with the leakage of radio wave out of the lane preferably suppressed.
(4) The lane controller will have the control units (transmission control unit, roadside RF unit) designed to have independent power ON/OFF function so as to allow the operation to continue even if the control unit gets partly out of order. In addition, the lane controller will have the backup memory.
(5) The license plate number recognizing unit as an optional function will recognize the license number plate data (size, color, RIKUSHI <area> code, vehicle-type code, usage code and sequence number) from the front of the vehicle photographed by the camera before transmitting the data together with the image data to the center computer system.

**4.3 Specifications for transit**

In the case of Hanshin Expressway Public Corporation, vehicles enter the area specified as transit zone by passing through the general roads.

Vehicles not using ETC system use the transit system by getting a transit ticket at the transit exit gate and submitting the ticket at the transit entrance gate, needing no collection of passage toll.

In the case of vehicles using ETC system, however, they get charged with the normal toll when they pass through the transit entrance gate.

Further, if the driver of a vehicle using ETC submits the transit ticket, he or she must have the collected toll paid back, making the passage of vehicles all the more complicated.

Hence it is necessary to record the transit exit data in the IC card mounted on the onboard equipment at the transit exit gate, and to read the data at the transit entrance gate to carry out automatic processing of transit.

(1) Processing at transit exit gate

The outline of ETC transit system is shown in **Fig. 3**.

(a) The lane controller receives the "transit exit table" from the center computer system.
(b) The roadside RF unit reads the "onboard equipment and IC card data" from the onboard equipment and

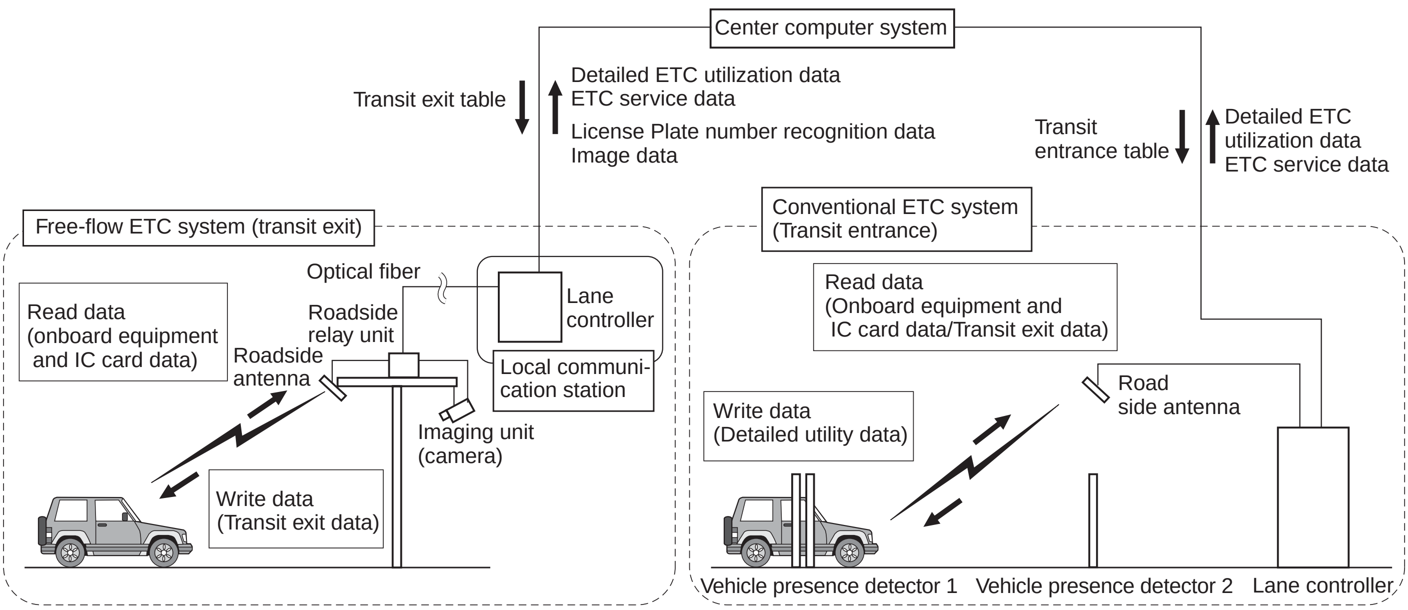


**Fig. 3 Outline of ETC transit system**

IC card.

(c) The roadside RF unit checks the validity of the onboard equipment and IC card.

(d) If found normal through the check, the "transit exit data" is written on the onboard equipment and IC card through RF communication.

(e) The transmission control unit prepares the detailed utility data and calculates the total number of passing vehicles through the result of the recognition made by the license plate number recognizing unit before transmitting the data to the center computer system. These data are also stored in the backup memory.

(f) The license plate number recognizing unit as an optional function transmits the license number plate recognition data of the passing vehicles together with the image data to the center computer system when inquiry or confirmation is made by the user.

(2) Processing at the transit entrance gate

(a) The lane controller receives the "transit entrance table" from the center computer system.

(b) The roadside RF unit activates the roadside antenna using the vehicle entrance signal to read the "onboard equipment and IC card data" and "transit exit data" from the onboard equipment and IC card.

(c) The roadside RF unit checks the validity of the onboard equipment and IC card.

(d) If found normal through the check, the "detailed utility data" is written on the onboard equipment and IC card of the transit vehicle using the RF communication.

(e) The transmission unit prepares the detailed utility data to transmit to the center computer system.

## 5. Features and achievements of the technology

### 5.1 Radio frequency (RF) communication technology

(1) Antenna design concept

In designing the antenna for free-flow ETC system (status quo, 2-lane) the following items were given substantial consideration.

(a) Ensuring high-reliability communication: Formation of communication range of lane width 6.6 m X length 4.5 m

(b) Reduction of garbage communication: Minimization of radio wave leakage to the adjacent lane

In order to satisfy the aforesaid two requirements there are two systems: the single antenna system that covers two lanes using one antenna by widening the antenna beam pattern and the multi-antenna system that covers multiple lanes using multiple antennas.

(2) Selection of communication system

The communication systems applicable to the free-flow ETC system are: (I) single antenna system, (II) double antenna system (frequency division multiplexing type), (III) double antenna system (time-division multiplexing type), and (IV) 3-antenna system (transmit/receive antenna separation type). The outline of the aforesaid systems (I)–(IV) is given in **Table 1**.

(3) Laboratory test result

Tests including function of the onboard equipment were carried out to confirm the optimum system out of the aforesaid systems (I)–(IV), with the outline of the laboratory test given in **Table 2**.

(4) Evaluation and study of communication system

It has been confirmed through laboratory tests that the aforesaid (I)–(III) systems could be applied. Of these systems, we came to conclusion that the double-antenna, frequency-division multiplexing system was optimum system from the standpoints of cost, maintainability and reliability.

**Fig. 4** shows the view of field test, while **Fig. 5** the


**Fig. 4 View of field test**
Example of communication zone measurement of free-flow ETC system antenna carried out at Futami Plant test course of Mitsubishi Heavy Industries, Ltd.

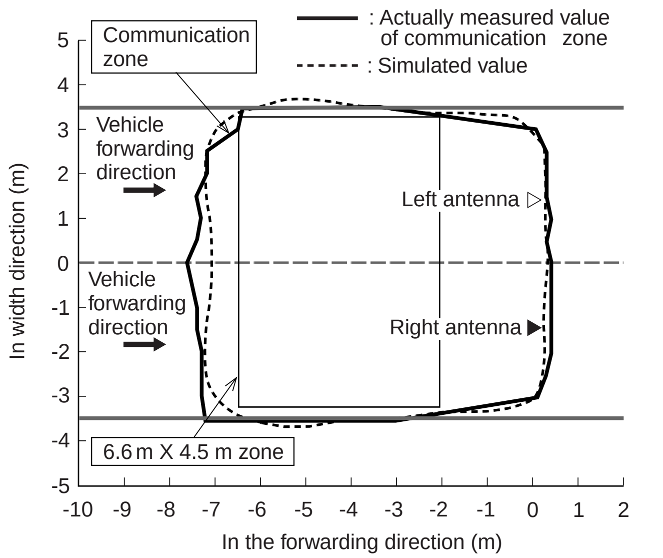



**Fig. 5 Results of simulation of double antenna combined communication zone and actual measurement**
Comparison between the simulated communication zone of the free-flow ETC system antenna and actually measured value (onboard equipment height: 1 m)

**Table 1 Outline of communication method**

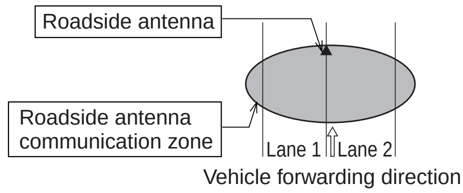
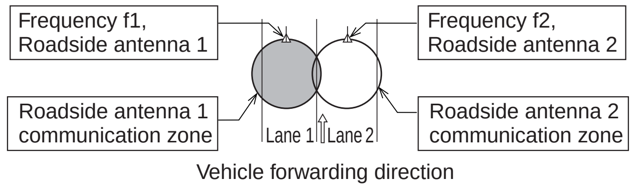
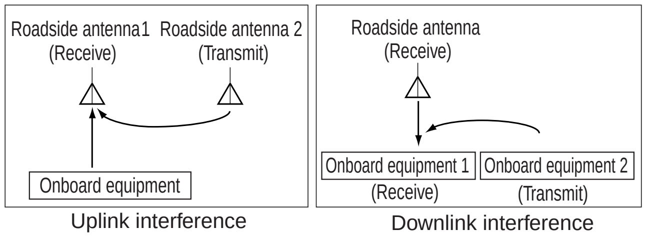
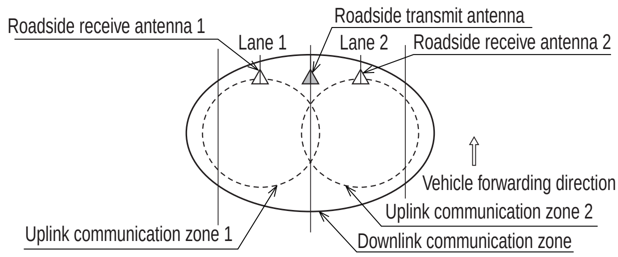
| System name | | Outline | Explanatory drawing |
|---|---|---|---|
| Single-antenna system | | A system that covers the communication zone equivalent to 2 lanes using one (single) antenna. It is necessary to change the number of elements of the current ETC antenna and to study the optimization of communication zone. However, the expansion of communication zone involves a problem of how to reduce the radio wave leakage to the neighboring lanes. |  |
| Double-antenna system | Frequency-division multiplexing (FDM) type | A system that can be applied, with the current ETC antenna left intact. Communication is made with the vehicles running on two lanes by using two antennas with different frequencies. There is no need of optimization of communication zone since each lane is covered by a different antenna, but needs verification about the interference from the neighboring channel. |  |
| | Time-division multiplexing (TDM) type | A system that applies the current ETC antenna as it is, with the communication made using two antennas with the same frequency by switching the timing for transmitting/receiving the signal. As shown in the figure, it is necessary to carry out verification that there is no radio interference from the neighboring antenna or onboard equipment. |  |
| Triple-antenna system | Transmit/ receive antenna separation type | As shown in the figure, this system separates the transmit antenna from the receive antenna, with the one transmit antenna covering the downlink area of multiple lanes, while the receive antennas installed one on each lane covering the uplink area. This system has an advantage that the overall communication zone can be limited by reducing the uplink area. |  |

**Table 2 Results of evaluation of each system**

| System name | | Test results | Evaluation |
|---|---|---|---|
| Single-antenna system | | Communication zone: Communication zone of width 6.6 m X length 4.5 m or over is available.<br>Radio wave leakage: Although designed to minimize the leakage, the radio wave leakage is substantial. | ○ |
| Double-antenna system | Frequency-division multiplex-ing (FDM) type | Communication zone: Communication zone of width 6.6 m X length 4.5 m or over is available.<br>Radio wave leakage: Designed to minimize the leakage, the (radio wave) leakage is limited.<br>Others: The communication zone is confirmed to have no effect from the neighboring antenna with different frequency. | ◎ |
| | Time-division multiplex-ing (TDM) type | Communication zone: Communication zone of width 6.6 m X length 4.5 m or over is available.<br>Radio wave leakage: Designed to minimize the leakage, the (radio wave) leakage is limited.<br>Others: No uplink interference and practically no downlink interference were observed. However, this system requires about twice longer time for communication. | △ |
| Triple-antenna system | Transmit/ receive antenna separation type | Communication zone: Communication zone of width 6.6 m X length 4.5 m or over is available.<br>Radio wave leakage: Substantial as the leakage is, there is little chance of communication being made with the vehicle running on the neighboring lane because the uplink communication zone is limited.<br>Others: Interference takes place when data are combined between the two antennas, needing a circuit to avoid the interference. | × |

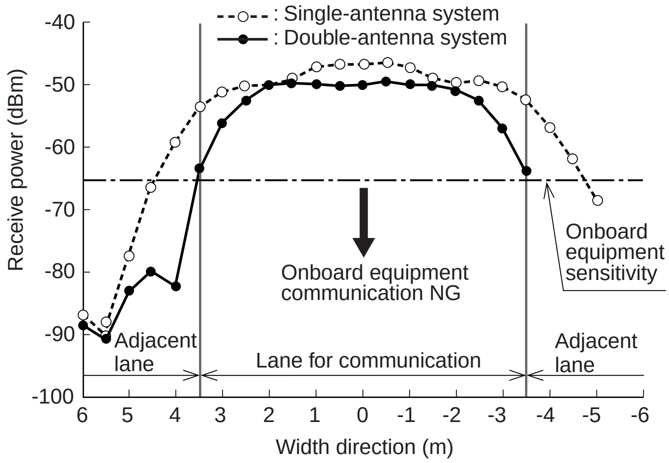



**Fig. 6 Radio wave (frequency) leakage to adjacent lane**
Results of measurement of field intensity distribution in the direction of lane width using single-antenna and double-antenna systems (position in forwarding direction: 3 m)

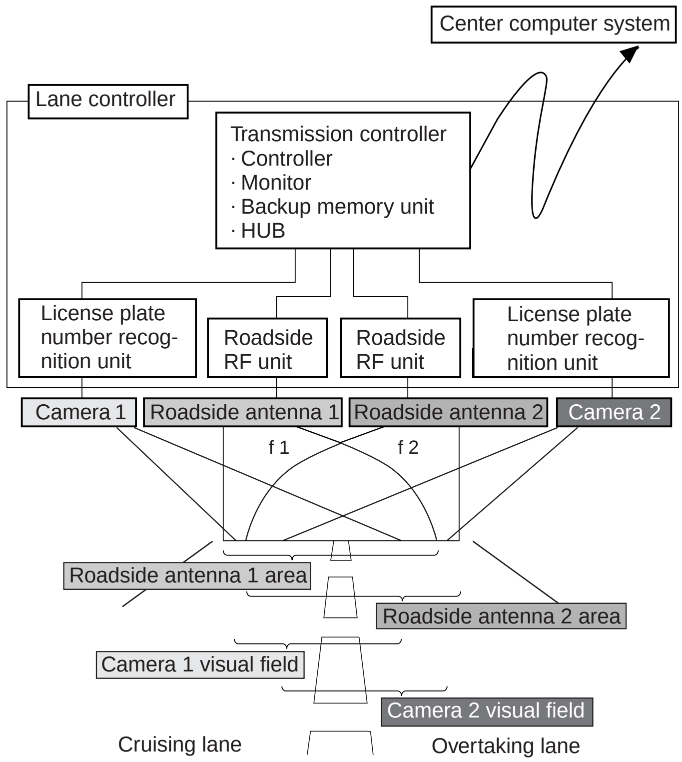



**Fig. 7 Schematic diagram of equipment configuration**

results of field test of the double-antenna, frequency-division multiplexing system. As shown in the figure, the communication zone shows excellent conformity in simulation result and actually measured value, indicating that the desired communication zone has been obtained.

**Fig. 6** shows the measured (obtained) value of field intensity in the direction of lane width. It has been confirmed the double-antenna type has approximately 10 dB less leakage of radio wave (frequency) to the adjacent lane at the end of the lane than the single-antenna type, reducing the garbage communication (error communication) with the vehicles running on the neighboring lane.

(5) Development achievement

The desired achievements could be obtained as shown in **Table 3**. Thus the RF communication unit was decided to adopt the double-antenna, frequency-division multiplexing system to ensure the features given below.

(a) The present ETC antenna can be applied simply by changing the installation conditions, ensuring high cost performance.

(b) The frequency-division multiplexing system provides the communication time equivalent to that of single-antenna type, ensuring high reliability even for vehicles running at high speed.

(c) Compared with single-antenna type, it has less leakage of radio wave to the adjacent lane, with extremely low error communication with the other vehicle.

### 5.2 High-reliability technology

(1) Duplexing system configuration

Unlike the conventional ETC system, the free-flow ETC system requires non-stop round-the-clock unmanned operation. In order to realize this, the free-flow ETC system was compared of the machines (devices) shown in **Fig. 7** to ensure high reliability.

**Table 3 Achievements of development**

| Item | Target value | Achievement | Remark |
|---|---|---|---|
| Reliability of communication (error rate) | $10^{-6}$ or under (on radio lane: $10^{-5}$ or under) | $10^{-6}$ or under obtained (on radio line: $10^{-5}$ or under) | – |
| Communication zone | Width 6.6 m X length 4.5 m | Communication zone of Width 6.6 m X length 4.5 m obtained | Double-antenna type, onboard equipment height: 1.0 m |
| Maximum speed | 90 km/h | 90 km/h or more | At the center of the lane |
| Radio wave (frequency) leakage to the neighboring lane | No communication made with the vehicle running on the neighboring lane (left/right 3.5 m or above in the direction of width) | The obtained onboard equipment receive power on the neighboring lane is –64 dBm or under (the chance of communication being made with the vehicle running on the neighboring lane is extremely small). | – |

**Table 4 Reliability at trouble occurrence**

| Trouble item | Reliability |
|---|---|
| Center computer system – Lane controller (transmission controller) circuit trouble (error) | The lane controller can be operated as usual. The ETC service data, detailed ETC utilization data and license plate number recognition data are stored in the lane controller (transmission controller) to be transmitted to the center computer system once the system returns to normal state. |
| Circuit trouble inside the lane controller (transmission controller – license plate number recognizing unit) | The roadside RF unit constantly activates the roadside antenna to send RF communication data to the transmission controller, so that the ETC service data and detailed ETC utilization data are transmitted to the center computer system as usual.<br>The license plate number recognizing unit saves the recognized (detected) data and sends the data to the transmission controller after the line returns to normal state. |
| Circuit trouble inside the lane controller (transmission controller – roadside RF unit) | The roadside RF unit stores the RF communication data to send it to the transmission controller after the line returns to normal state.<br>The license plate number recognizing unit transmits the recognized data to the lane controller (transmission controller), so that the license plate number recognized data is transmitted to the center computer system in the usual manner. |
| Lane controller (license plate number recognizing unit) trouble, camera trouble | The roadside RF unit transmits the RF communication data to the lane controller (transmission controller), so that the ETC service data and detailed ETC utilization data are sent to the center computer system as usual.<br>The license plate number recognized data is not created because of the machine trouble. |
| Lane controller (roadside RF unit) trouble, roadside antenna trouble | The system can be continuously operated in spite of the trouble occurrence in one of the RF units or in the roadside antenna. However, because of the characteristic of the roadside antenna, the lane at the side end gets out of the communication zone.<br>The trouble in both roadside RF units and roadside antenna cripples the roadside system, making its operation impossible. |
| Equipment maintenance | The roadside RF unit and the roadside antenna can be put to maintenance alternately to allow the system to continue operation. However, because of the characteristic of the roadside antenna, the lane at the side end gets out of the communication zone. |

Further, the lane controller constantly monitors the component machine, and should some error occur, it is informed immediately to the remote monitor installed on the center computer system.

The likely error items and the reliability are summed in **Table 4**. The system is equipped with backup memory at the local (individual) equipment, saving the data and ensuring continuous operation even when something goes wrong with the host equipment. The reliability of toll collecting system has thus been greatly improved by adopting the duplex equipment and having step-wise backup memory.

(2) Function to prevent the user from being double charged

The free-flow ETC system adopts duplexing system with each of the roadside antenna having the communication zone covering 2 lanes. Thus, the onboard equipment of a vehicle could make communication with another antenna after completing communication with the first roadside antenna, leading to the driver's getting double charged. In order to prevent this double charging, the lane controller is installed to check the read data.

## 6. Conclusion

The newly developed free-flow ETC system has started operation at 4 exit gates since July 2002 as the transit ETC system for Hanshin Expressway Public Corporation.

An ETC system for special zone toll collection, adopting a new imaging system, is to be introduced by the end of the fiscal year 2002. Further, the system is planned to expand the service to allow the vehicles ETC transit through the ETC of Kobe Municipal Road Corporation lying on the transit route from Kita Kobe Route No. 7 to Kobe Route No. 3 by improving the present transit function.

Further, this system is applicable not only to the off ramps of urban expressways, but also to the newly constructed entrance gate/exit gate and as the unmanned toll collecting system for other road public corporations and institutes.

Finally, the appropriate introduction of the free-flow ETC system in the future will make it easy to adopt the road pricing system and to allow a shift to diversified toll collecting systems such as from the present open system to closed system.

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