

# Development and Evaluation of ITS Information Communication System for Electric Vehicle

Yuriko Hattori, Tomokazu Shimoda

ITS Department, Transportation Systems & Advanced  
Technology Division  
Mitsubishi Heavy Industries, Ltd.  
Kobe, Japan  
[yuriko\\_hattori@mhi.co.jp](mailto:yuriko_hattori@mhi.co.jp)

Masayoshi Ito

Electronics Engineering Dept., Development Engineering  
Office  
Mitsubishi Motors Corporation  
Okazaki, Japan

**Abstract**—Electric Vehicle (EV) has a restriction for the distance which it can drive by one battery charge, and under the present situation there are some problems such as there being few installation places for the battery charge equipment. To promote the introduction of EV, the ITS services corresponding to these problems and characteristics are required. “ITS information communication system for EV” we propose in this paper, provides functions for observing the amount of battery remainder and leading to surrounding battery charge stations while driving, and also efficient battery charge management. Concretely we develop the protocol that connects the wide area network and the road to vehicle communication with the in-vehicle network, and also the in-vehicle system and the roadside system whereby reading and writing vehicle data from center and roadside are achieved. As a result of the feasibility test, the sense of security in the EV and the convenience and the amenity in the battery charge stations will be improved. The effectiveness of the services and practical use of the system have been confirmed.

**Keywords**—component; On-board unit (OBU); Road to vehicle communication; Wide area network; In-vehicle network; and Electric vehicle (EV)

## I. INTRODUCTION

In order to achieve a low carbon society, the introduction of EV that considers the environment is being promoted. EV has a restriction for the distance which it can drive by one battery charge, and under the present situation there are few installation places for the battery charge equipment. Moreover, the multiple users often share one EV and there are some problems such as the idea of ordinary fueling not applying to EV. On the other hand, EV has the characteristics such as electricity can be used while stopping and the communication network can be built in easily. To promote the introduction of EV, it is necessary to provide the ITS services corresponding to these problems and characteristics.

“ITS information communication system for EV” we propose in this paper is expected observing the amount of battery remainder and leading to surrounding battery charge stations while driving, and doing efficient battery charge management of EV in battery charge stations. For such a system, a high-speed and high-quality, and high-security means

of communication is required by connecting an external communication network and an in-vehicle network. In this case, subjects of the system are following two points.

- Detecting abnormality in vehicle immediately and providing the information surely in vehicle.
- Control vehicle remotely in real time by operating the vehicle state.

Up to now, the method of using the wide area network such as cellular phones has been put to practical use as a vehicle state monitoring system. When abnormality in vehicle is detected, information is collected to an information center by a wide area network. However, though abnormality is notified outside the vehicle and the center generates information and delivers it, it is difficult for the drivers and the vehicle managers to correspond at once. Moreover, a system that uses an inter-vehicle communication as a communication network is researched. The vehicle installed OBU (On-Board Unit) should exist in surrounding area, and it is impractical considering current conditions of spreading OBU with inter-vehicle communication function.

In this paper, to solve these problems we propose the ICT (Information Communication Technology) system that combines a wide area network and a road to vehicle communication. When detecting abnormality in vehicle by a wide area network and a road to vehicle communication at once, the vehicle state is operated from a center and a roadside wireless device, and it enables to correspond at once by controlling vehicle remotely in real time. Concretely, the communication protocol that connects a wide area network and a road to vehicle communication with an in-vehicle network was developed. Additionally the in-vehicle system and the roadside system were developed, which achieved reading vehicle data and controlling vehicle remotely via OBU from the center and the roadside wireless device. Executing the feasibility test by the experimental system, it has been confirmed to be able to improve the sense of security in the EV and the convenience and the amenity in the battery charge stations. The effectiveness of the services has been evaluated.

## II. RELATED STUDIES

As for ICT practical deployment for vehicle in Japan, telematics integrated the cellular phone and the navigation system and the safe driving assistance system using the road to vehicle communication have been put to practical use. For telematics mobile WiMAX in addition to 3.5G cellular phone system is used. For the safe driving assistance system, "ITS Spot Services" adopting 5.8GHz DSRC (Dedicated Short Range Communication) road to vehicle communication in addition to existing VICS (Vehicle Information Communications System) deliver the road traffic situation and the preventive safety information to the ITS OBU with ETC (Electronic Toll Collection System) function.

As for vehicle state monitoring systems, wide area communication systems that gather information to the information center using the wide area network such as cellular phones. Moreover inter-vehicle communication systems are researched where generate and deliver information via OBU, using the inter-vehicle communication with radio communications equipment of wireless LAN etc. Though wide area communication systems have little restriction concerning the service area, information provision is pull type, and it is unsuitable for providing information on push type to all vehicle that exist in a specific area. Moreover, it is useful for services to make users feel additional value because communication cost is necessary. As for inter-vehicle communication systems, the communication range of radio wave is about 100m when wireless LAN is used. If the vehicle installed OBU do not exist within the range, it is impossible to exchange information. On the other hand, in the case of the vehicle existing within the range, it is possible to exchange information directly without the information center, and immediacy is excellent character. While road to vehicle communication systems, the service area is limited within neighborhood about 30m from roadside devices. However, information can be collected in real time from vehicle in the communication area and information on push type can be provided surely at the same time, these are advantages. Moreover, security is high because of the communication with the limited roadside devices. On the other hand, when the service coverage is an area, installation cost for roadside devices is necessary. In this paper, we propose the system that makes the best use of both advantages to combine wide area communications and road to vehicle communications.

## III. PROBLEM SETTING AND REQUIRED CONDITIONS

### A. Road to Vehicle Communication

As for the road to vehicle communication, 5.8GHz DSRC is adopted that is used for ETC in Japan. DSRC is compliant with ARIB STD-T75 [1], STD-T88 [2]. The communication area of DSRC is comparatively narrow, the transmission speed is fast (4Mbps), and these are the feature of DSRC. DSRC composes a steady communication zone that is the range of 30m in the center of the base station position. One base station communicates simultaneously with multiple mobile stations, and it is likely to communicate unstable because the situation of radio communication lines is deteriorated by shadowing etc.

### B. Wide Area Network

As for the wide area network, 3.5G communication line is adopted that is the main current now. 3.5G has already provided services and widespread to urban district of the advanced countries. Real time communication is necessary for up-link of vehicle information and providing information to drivers timely. It is assumed the method that can be connected continuously as much as possible even in suburbs and mountainous district. The transmission rate is about 100kbps for the up-link of vehicle information, and it is possible to use it without feeling stress for providing information to drivers if it is 1Mbps.

### C. In-Vehicle Network

As for the in-vehicle network, CAN (Controller Area Network) is adopted. CAN is the serial communications protocol to which is international standardized by ISO 11898 [3]. It is the typical LAN protocol for vehicle widespread to the cars in Japan. It is also applied to the control system in Europe. CAN is differentiated to control system CAN (high speed system) and body system CAN (low speed system) according to the usage. For instance, in bus interface (communication) circuit, the 2-wired system differential voltage type circuit is adopted in the low speed system and the 2-wired system equilibrium current type circuit is adopted in the high speed system. CAN is the bus arrangement of the multiple master methods that all connected units can begin the message transmission used CSMA/CR (Carrier Sense Multiple Access with Collision Resolution), where the unit can obtain the transmission right which begins transmitting first for the bus. 1Mbps or less communication is possible in the high-speed.

### D. Required Conditions

The ITS information communication system for EV we propose in this paper is the system corresponding to problems and characteristics of EV, where a high-speed and high-quality, and high-security means of communication is required by connecting an external communication network and an in-vehicle network. Here, required conditions that the system should meet are as follows.

- It should be able to collect the vehicle information such as the amount of battery remainder and the driving history etc. according to arbitrary timing while driving. It should be able to provide information in vehicle without operation.
- Vehicle state should be operated, and vehicle should be controlled remotely in real time. Time from the communication connection to the beginning controlling is short, and the transmission of information must be high-speed and low latency.
- Providing information corresponding to the composition and the ability of in-vehicle systems must be possible. Single OBU system, the combined smart-phone system, and the combined car navigation system with comparatively high resources, it should correspond to various in-vehicle systems.

- High-security transmission of information must be possible.
- There is no change to device composition in addition and enhancing services. It is necessary to be able to correspond by adding and changing the application software.

#### IV. PROPOSAL OF ITS INFORMATION COMMUNICATION SYSTEM FOR EV

We propose the ITS information communication system for EV that uses a wide area network, a road to vehicle communication, and an in-vehicle network as a system that satisfies the required conditions arranged in the previous chapter. For the proposed system, DSRC is adopted as a road to vehicle communication, 3.5G communication line is adopted as a wide area network, and CAN is adopted as an in-vehicle network.

##### A. System Configuration

The ITS information communication system for EV is composed of an information center, a roadside system, a roadside wireless device (antenna), OBU, an information provision device (car navigation system, smart-phone), and an EV. OBU interfaces with a car navigation system, a vehicle ECU (Electronic Control Unit), and a wide area network. This system controls the ECU by CAN interface, and provides information to the car navigation system. The center and the roadside antenna communicate with OBU periodically. When abnormality in vehicle is detected, the system provides information in vehicle. Additionally the vehicle state is operated via OBU, and the system controls vehicle remotely. Figure 1 shows the system configuration of the ITS information communication system for EV.

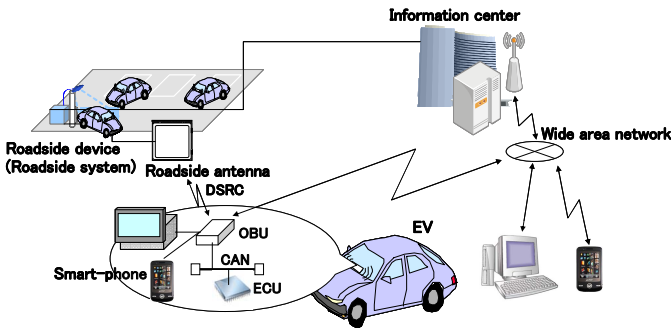


Figure 1. Configuration of ITS information communication system for EV.

##### B. Communication Protocol

We develop the communication protocol that connects DSRC and 3.5G communication line with CAN and combines DSRC and 3.5G communication line. The communication platform is constructed, which added communication not only for road to vehicle but interconnection with a wide area network and an in-vehicle network.

###### 1) Protocol Stack:

Figure 2 shows the protocol stack that connects roadside system, in-vehicle system, and in-vehicle network for the ITS information communication system for EV proposed in this

paper. The information provision application (AP) and the vehicle state monitoring application in the roadside system are constructed as the DSRC application where the DSRC communication platform is located on the lower layer [4]. This enables to achieve reading vehicle data and writing vehicle control data on an in-vehicle network from the vehicle state monitoring application in the roadside system via CAN interface (I/F) of an in-vehicle system. Moreover, it is assumed that an in-vehicle system is composed of OBU and the external device such as car navigation system, and the applications in an in-vehicle system are composed of two layers such as the protocol processing of road to vehicle communication and the information provision application. Additionally, the interface with the car navigation system and the wide area network are prepared, and it is enabled to be installed the information provision application on the car navigation system.

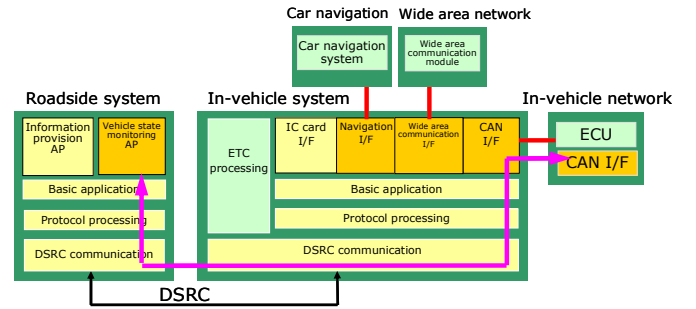


Figure 2. Protocol stack.

###### 2) Communication Sequence:

###### a) Communication sequence for connecting roadside with in-vehicle network

The communication sequence for connecting a roadside system with an in-vehicle network enables to achieve reading vehicle data and writing vehicle control data on an in-vehicle network from the roadside application via an in-vehicle system.

- Vehicle data reading sequence

The CAN interface of OBU reads message ID and data from the CAN bus, and stores and updates them in the CAN receiving memory. The OBU control part refers to the CAN receiving memory periodically, takes out the receiving data corresponding to message IDs which are registered in the OBU control part, and registers it in the memory tag as the vehicle status information. The roadside system reads the data from the memory tag of OBU by "Memory reading request command". The OBU control part initializes the content of the memory tag after memory reading request command terminates normally. It is required to collect the vehicle status information via the OBU by CAN interface at sampling intervals of 1second or less.

- Vehicle control data writing sequence

The roadside system writes the vehicle control commands in the memory tag of OBU by "Memory writing request command". The OBU control part converts the vehicle control commands into the ECU commands, transmits them by CAN interface. The conversion table of the vehicle control commands and the ECU commands is prepared because the

ECU commands arrangement might be different in each model. The OBU control part transmits the execution results of the ECU commands from the DSRC section of OBU to the roadside system, and responds to the roadside system by "Memory writing response command" when the ECU commands terminate normally. "OBU negative acknowledgement command" is returned to the roadside system when failing.

*b) Communication sequence for connecting wide area with in-vehicle network*

The in-vehicle system sends up-link of the vehicle status information to the center periodically using a wide area network. The up-link of vehicle status information has the role as polling to confirm the presence of transfer information to an in-vehicle system for the center system. The center system sends URI (Uniform Resource Identifies) information to the in-vehicle system if necessary as the response for the vehicle status information up-link. URI information is used to identify information that the center system provides to the in-vehicle system. The in-vehicle system transmits URI to the center system, and receives the contents and information for the car navigation system.

*c) Communication sequence for combining road to vehicle with wide area communication*

When the OBU enters in the communication area, the roadside system transmits URI information for the car navigation system if necessary by push type information provision using the road to vehicle communication. The in-vehicle system connects with URI by the wide area network, and receives the contents and information for the car navigation system. By combining a road to vehicle communication with a wide area communication, it enables to provide the local information around the roadside devices such as the battery charge stations and the shops advertisement timely to in-vehicle system.

## V. DEVELOPMENT OF IN-VEHICLE AND ROADSIDE SYSTEMS

To evaluate the effectiveness of the ITS information communication system for EV proposed in the previous chapter by the feasibility test, an experimental system has been developed. This chapter describes mounting concretely of the in-vehicle system and the roadside system.

### A. In-Vehicle System

An in-vehicle system includes OBU and the interfaces of a car navigation system, a vehicle ECU, and a wide area network connected to OBU. The in-vehicle system collects the specified vehicle information that connected with an in-vehicle network, and controls ECU by CAN interface. The in-vehicle system communicates with a roadside wireless device by DSRC, and gathers the vehicle information to a center using a wide area communication interface. The in-vehicle system also mounts the function for providing information to a car navigation system.

#### 1) On-Board Unit (OBU)

The OBU is compliant with DSRC section standard specification of ITS OBU [5], and possesses the functions for DSRC communication, a wide area network connection, ECU connection, and a car navigation connection. Moreover, the OBU can start by DSRC communication while parked (state of ignition OFF). The electric power consumption of the OBU on standby mode is low enough, the OBU have the function for shifting to the state of low power consumption while parked and the wake-up function by detecting the electrical change of transmission line.

#### 2) ECU Interface

The interface with ECU is mounted to observe the vehicle state from the center and the roadside system, and to control vehicle remotely. Using basic applications of the DSRC platform, the ECU interface reads the specified vehicle status information and writes the vehicle control data from the center and the roadside system by CAN interface. The communication sequence follows the communication protocol that connects DSRC with CAN.

The electric specifications for CAN interface are compliant with ISO 11898-2 [6] and 11898-3 [7]. The communication parameters are compliant with both CAN-B (low speed system) and CAN-C (high speed system). A high-speed transmission rate is 500kbps, and a sampling interval is 500msec. The access to ECU excluding specific roadside wireless devices is prevented, and a high-security information transmission is enabled. Reading and writing to the communication control part from roadside system should be accepted only by the memory access of basic applications via DSRC security platform (DSRC-SPF). In addition, the password is set to the memory tag, and only specific roadside wireless devices can read and write the ECU data and the vehicle status information which are prevented tapping and being falsified.

#### 3) Wide Area Communication Interface

The interface with a wide area network is mounted to observe the vehicle state from the center system, and to transmit the vehicle status information to the center periodically, moreover to provide information to the car navigation system. Using the wide area communication interface, the uplink information such as battery charge remainder and driving histories etc. is collected, the down-link information such as charge facilities etc. is provided and the Internet connection by HTML is done.

#### 4) Car Navigation Interface

The interface with a car navigation system is mounted to provide information from the center and the roadside system to a car navigation system. Using the car navigation interface, the down-link information such as traffic information etc. is provided, the up-link information such as driving histories etc. is collected, and the Internet connection by HTML is done.

The communication method is USB version 1.1 or more. The USB device is OBU and the USB host is the car navigation system. The effective transmission rate is assumed to be 4Mbps or more. The communication control part corresponds to multiple data forms and applications using the data forms such as basic applications and PPPCP (Point-to-Point Protocol Control Protocol) etc. After receiving data in DSRC section,

the data transfer delay to the communication part is assumed to be 10msec or less.

## B. Roadside System

A roadside system includes an information provision application, a vehicle state monitoring application, and a roadside wireless device (antenna). The functions for observing the vehicle state from the vehicle state monitoring application in the roadside system via the in-vehicle system, controlling vehicle remotely, and providing information in vehicle are mounted.

The information provision application generates the down-link information provided to the car navigation system. The vehicle state monitoring application possesses as basic functions for reading vehicle IDs from the roadside wireless devices, confirming the registered vehicle, and reading and writing the vehicle information by CAN interface. Additionally, the vehicle monitoring functions and the service functions based on vehicle information are mounted. As one example of the vehicle state monitoring application, the vehicle monitoring function and the service function mounted this time are described as follows.

### 1) Vehicle Monitoring function

The vehicle monitoring function operates observing based on vehicle information (amount of battery charge, state of air conditioner switch etc.) that the center and the roadside system receive from OBU. Table 1 shows one example of the vehicle information items handled by the vehicle monitoring function. The center and the roadside antenna communicate with OBU periodically, observe the items in Table 1, and the state is displayed on the screen of the center and the roadside system.

TABLE 1 EXAMPLE OF VEHICLE INFORMATION ITEMS.

Items	Contents
Amount of battery charge	Battery charging ratio (%)
EVoutput	(W)
Air conditioner switch	ON/OFF
Head lamp switch	ON/OFF
Shift switch	Drive/Eco/Brake
State of battery charging	OFF/100vAC/200vAC
Rapid type battery charging	Normal/Rapid
Driving speed	(km/h)
Driving distance	(km)
Direction indicator	OFF/Right turn/Left turn/Hazard
Brake lamp switch	ON/OFF

### 2) Service Function

The service operation of the service function based on the vehicle information is described as follows.

#### a) Function for guidance to battery charge stations

When the amount of battery remainder goes below the threshold, it is judged the amount of battery remainder has become shortage. The center and the roadside system display warning, and warning output are sent to the car navigation in vehicle. Depend on the distance which it can drive based on the amount of battery remainder, the location and the use state of surrounding battery charge facilities are provided to the car

navigation system. The car navigation system guides the driver.

#### b) Function for efficient battery charge management

The center system manages the amount of battery remainder of EV. By synchronization with the battery charge reservation system in battery charge stations, an appropriate battery charge method (Rapid/Normal) is selected depending on the time until the next utilizing of EV and battery charging for vehicle is operated remotely (Start and Stop). Moreover, the air conditioner is operated beforehand before a driver gets in.

## VI. FEASIBILITY TEST BY EXPERIMENTAL SYSTEM

### A. Experimental System Configuration

The experimental system of the ITS information communication system for EV is composed of a center system, a roadside system, a roadside wireless device (antenna), OBU, a car navigation system, and a vehicle. Observing the vehicle state and the service function based on the vehicle information are operated from the center and the roadside system. Testing was executed in a stable radio propagation environment by the prospect in the outdoor test course.

### B. Evaluation of Experimental System

#### 1) Functional evaluation

##### a) Confirmation of vehicle monitoring function

Vehicle IDs are read by the communication result of the center and the roadside antenna with OBU. The center and the roadside system detect the registered vehicle, and it has been confirmed that the state of the vehicle information items in Table 1 is displayed on the screen of the center and the roadside system at the same time.

##### b) Confirmation of function for guidance to battery charge stations

When the state of the EV battery charging ratio 30% or less is generated, the center and the roadside system detect the amount of battery remainder shortage, and warning is displayed. It has been confirmed to send warning output to the car navigation in vehicle. When the vehicle is not registered, it distinguishes with vehicle ID, and even if the state of the battery charging ratio 30% or less is generated, it was verified not to send warning output to the car navigation system. In addition, it has been confirmed that the location and the use state of surrounding battery charge facilities were provided surely to the car navigation in vehicle.

##### c) Confirmation of function for efficient battery charge management

The center system manages the amount of battery remainder of EV. It has been confirmed that the battery charge method (Rapid/Normal) is selected depending on the time until the next utilizing of EV, battery charging for vehicle is operated remotely (Start and Stop), and the air conditioner is operated beforehand before a driver gets in.

#### 2) Performance Evaluation



### a) Evaluation of Performance for Collecting Vehicle Information

Performance of the experimental system for collecting vehicle information is evaluated by the communication test. Registered vehicle is distinguished by vehicle ID and time for collecting 1Kbytes vehicle information using 3.5G communication line or DSRC is measured. Figure 3 shows the distribution of processing time that is added sampling intervals of 500msec by CAN interface. Because of adopting high speed CAN and combining 3.5G communication line with DSRC, the cumulative distribution where the center and the roadside system collect the vehicle information within 1second via the OBU is about 100%. It has been evaluated to collect the vehicle information at sampling intervals of 1second or less by the experimental system.

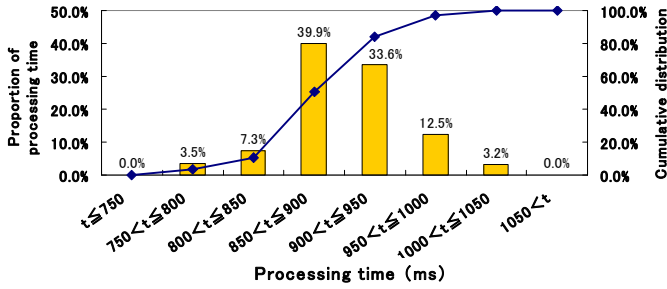


Figure 3. Distribution of time for collecting vehicle information by experimental system.

### b) Evaluation of Performance for Providing Information

The state of the EV battery charging ratio 30% or less is generated, the center and the roadside system detect the amount of battery remainder shortage, and processing time until sending warning output to the car navigation in vehicle is measured. By using the communication protocol that connects 3.5G communication line with CAN, the cumulative distribution where processing time until sending warning output to the car navigation system after the amount of battery remainder has become shortage is within 3seconds is about 100%. Performance for providing information in vehicle by the experimental system has been evaluated.

### c) Evaluation of Performance for Controlling Vehicle Remotely

Performance of the experimental system for controlling vehicle remotely is evaluated by the communication test. Registered vehicle is distinguished by vehicle ID and processing time for operating the air conditioner to switch on using DSRC and CAN interface is measured. Because of adopting high speed CAN and using the communication protocol that connects DSRC with CAN, the cumulative distribution where the roadside system operates the air conditioner to switch on within 3seconds via the OBU is about 100%. It has been evaluated to operate the air conditioner beforehand before a driver gets in by the experimental system according to the schedule for the charge facilities.

## VII. CONCLUSIONS

In this paper, to provide the ITS services corresponding to problems and characteristics of EV we propose the ITS information communication system for EV that uses a wide area network, a road to vehicle communication, and an in-vehicle network. DSRC is adopted as a road to vehicle communication, 3.5G communication line is adopted as a wide area network, and CAN is adopted as an in-vehicle network, and we have developed the communication protocol that connects DSRC and 3.5G communication line with CAN and combines DSRC and 3.5G communication line. Moreover the in-vehicle system and the roadside system have been developed, which achieved reading vehicle data and controlling vehicle remotely via OBU from the center and the roadside wireless device.

Executing the feasibility test by the experimental system, the center and the roadside system detect abnormality in the vehicle, and it has been confirmed to provide information surely in the vehicle. In addition, it has been confirmed to control the vehicle remotely in real time by operating the vehicle state from the center and the roadside system, and to be able to improve the sense of security in the EV and the convenience and the amenity in the battery charge stations. The effectiveness of the services has been evaluated.

The practical use evaluation of the ITS information communication system for EV will be done in the future. Combining with another communication media system such as an inter-vehicle communication etc. will be enabled. Moreover, services using the EV communication network, and the usage of EV as an information infrastructure will be enabled.

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