Automatic train control system for the Shinkansen utilizing digital train radio

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Abstract

An ATC (Automatic Train Control) system utilizing digital train radio for the Shinkansen line has been developed. LCX (leaky coaxial cable) system along the track transfers information for train control such as: train location information from the on-board ATC system and distance-to-go information from the ground-side train protection equipment. Applying the developed technology, it is expected that track circuits in the section between switch stations become unnecessary for train separation control. The quality of digital communication by LCX and the accuracy of train location measured by trial tests were both sufficient enough to put the system into practical use. East Japan Railway Company decided to apply the technology for the substitute block system of the Tohoku and Joetsu Shinkansen lines with a future scope that the system will become the major train protection system of Shinkansen lines.
Keywords: Automatic Train Control, digital train radio, LCX, substitute block system.

1 Introduction

As the Shinkansen trains run at super-high speeds, the cab signal system that sends speed signals to the driving cab has been used. And the Automatic Train Control (ATC) system has been used to control train speeds automatically in accordance with those speed signals. The ATC system of the Tohoku Shinkansen and Joetsu Shinkansen lines has contributed to the safe and stable transportation since the commencement of these lines in 1982. But the system is aged and the replacement of the ATC system is required.

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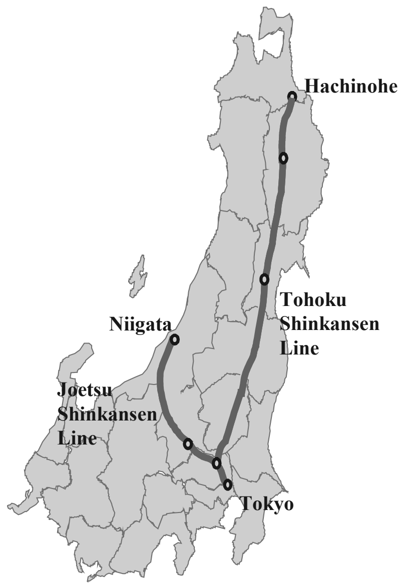

Figure 1: The Tohoku and Joetsu Shinkansen lines.

On the other hand, the mobile technology such as mobile cellular phone has dramatically advanced and it is expected to make use of the technology in railway signalling to reduce the construction cost.

Then we developed the ATC system utilizing digital train radio and decided to use the developed system as a substitute block system for the Tohoku Shinkansen and Joetsu Shinkansen lines.

2 ATC system utilizing digital train radio

2.1 Digital train radio of the Shinkansen

The digital train radio of the Tohoku Shinkansen and Joetsu Shinkansen lines using a leaky coaxial (LCX) cable laid along the track was put into service on November, 2002. There are fifteen channels for data communications and four channels are assigned to the train control with the data transmission rate of 9600 bps. If a channel is used to control a train, only four trains can be controlled by the digital train radio. So the idea of time slots is adopted. A channel is divided twenty-five time slots per a second and the number of the trains controlled by the radio is increased.

2.2 Outline of the developed system

First on-board ATC device of the developed system gets the output of the tachometer-generator and calculates the location of the train at every time period. Then the calculated location information is transmitted by the LCX cable to the

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ground-side equipment. Next the ground-side train protection equipment identifies every train's location as the followings.

(1) When a train is with in a section between neighbouring stations, the train location information described above is used.

(2) When a train is within a station zone, the train detection information from track circuits is used.

After that the ground-side train protection equipment generates the distance-to-go information in accordance with the trains' location. Finally the ground equipment sends the distance-to-go information to the trains with the LCX cable independent of trains' location.

Applying the developed technology, it is expected that track circuits outside switch stations become unnecessary for train separation control. But there are several problems such as identification of switched off train to apply the developed system to normal block system. Then we used the developed system as a substitute block system.

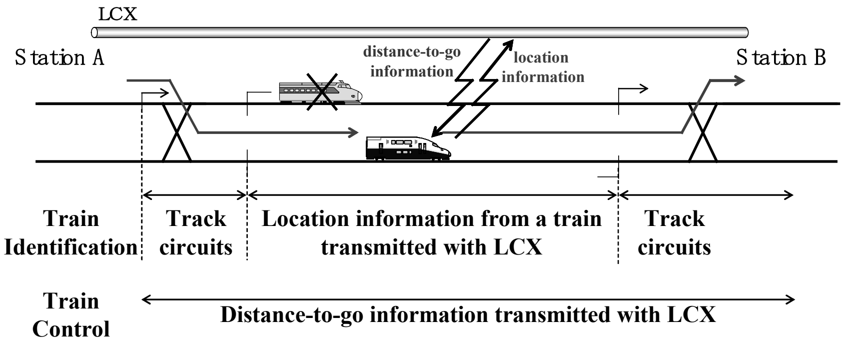

Figure 2: Outline of the developed system.

2.3 System configuration and functions

The system configuration is shown in fig.3. The outline of each function is described in the following.

2.3.1 Ground equipment

Ground equipment consists of a regular logic controller, a track communication server, a radio logic controller and a radio unit. The radio logic controller, the track communication server and the regular logic controller are connected with the optical cable at speed of 100Mbps.

2.3.1.1 Regular logic controller The regular logic controller is an integrated system of the functions of both regular block system and computerized interlocking device. If substitute block method is executed, it would interlock a route that connects a station and a next one and permit only one train to run on the route. The number of trains between neighbouring stations is counted by axle counters.

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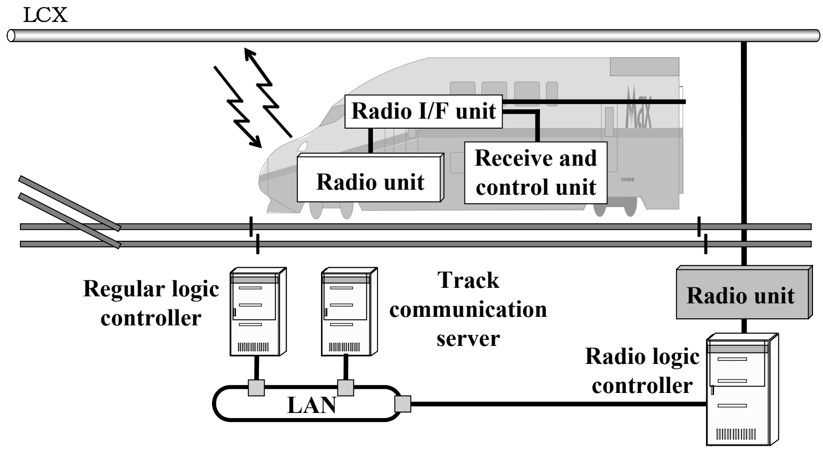

Figure 3: System configuration.

2.3.1.2 Track Communication Server (TCS) The TCS performs train detection based on the information received from transceiver furnished to every track. And it transmits the track occupancy state of the track within station zones to the radio logic controller.

2.3.1.3 Radio logic controller The radio logic controller is a main controller of the developed system. It identifies the every train's location with the information transmitted through the LCX cable from on-board device and the track occupancy state from the TCS. Then it makes the distance-to-go information in accordance with the trains' location and sends it to the trains through the LCX cable. Furthermore it administers the time slot of the train control channels of the digital train radio.

2.3.1.4 Radio unit The radio unit receives the train location information from the on-board device through the LCX cable and transmits the information to the radio logic controller. Furthermore it receives distance-to-go information from the radio logic controller and transmits the information to the on-board device through the LCX cable.

2.3.2 On-board equipment
The on-board equipment is composed of the following devices.

2.3.2.1 On-board radio unit The on-board radio unit receives the distance-to-go information from the ground equipment through the LCX cable and transmits the information to the radio interface unit. And it receives the train location information from the radio interface unit at every 1350 ms period and transmits the information to the ground equipment through the LCX cable.

2.3.2.2 Radio interface unit The radio interface unit receives the distance-to-go information from the radio unit at every 40 ms period. Because the ground equipment sends the distance-to-go information of all trains using a channel, the radio interface unit can receive the null information to itself. Then it must select the distance-to-go information for itself by the distinctive train number contained in the information. And it receives the location information from the reception and control unit and transmits it to the on-board radio unit.

2.3.2.3 Receive and control unit The reception and control unit has the both functions of the regular block system and the developed system. It identifies the precise train location by the output of the tachometer-generator and the transponder unit. It also controls automatically the train brake in accordance with a permissive speed profile obtained from the distance-to-go information. The profile data is stored in a database of on-board device beforehand.

2.3.2.4 Transponder unit The transponder unit receives precise position information from wayside coils installed approximately every three kilometres and outputs it to the receive and control unit.

Table 1: System specification.

Communication cycle time (per a train)	1350 ms
Data transmission rate (digital train radio)	9600 bps
Data length of distance-to-go information (per a train)	48 bytes
Error check (for the train control channel)	16 bits cyclic redundancy check
Number of channels (per a radio unit)	4 channels (Up and down line have each 2 channels)
Number of time slots (per a channel)	25 time slots
Number of radio logic controller (the Tohoku and Joetsu Shinkansen Lines)	26 units
Number of digital train radio units (the Tohoku and Joetsu Shinkansen Lines)	39 units
Average radio covering area (per a radio unit)	20 km

2.4 System specification

The system specification of the developed system shown in table 1 is described in the following.

(1) The distance-to-information that has the data length of 48 bytes consists of a time slot information, a train number, a preset block number, a stopping block number, a train protection information and so on.

(2) The communicating information between the ground equipment and the on-board device is subject to a 16 bits cyclic redundancy check (ITU-T CRC 16).

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(3) Two time slots of twenty-five time slots per a channel are used as poling-slots that are utilized by the ground equipment to identify a train at the first time that the on-board device is turned on. The remaining twenty-three time slots are utilized as control-slots, so maximum number of trains controlled by a channel is twenty-three.

3 Train control using digital train radio

3.1 Train identification

The flow how the ground equipment identifies the train location by the digital train radio is described in the following.

(1) The ground equipment transmits the poling-information at every 1350 ms period to communicate the trains at the first time that the on-board device is turned on.
(2) The on-board device that has not been assigned time slots received the poling-information and answers the train's location using poling-slots. The train's location is obtained at first by the ATC telegram for regular block system using track circuits.
(3) The ground equipment receives the answer on the poling-slot. Then it confirms that the location contained in the answer is correct or not by the information from TCS. If the location information that the on-board device answers corresponds with the information of TCS, it sets the train number information in the answer to control-slot that isn't utilized at present.
(4) The on-board device compares its train number and the train number of the distance-to-go information. If the result agrees, it would control the train based on the information from the ground equipment.
(5) The ground equipment has been communicating with the on-board device until the train has run out beyond the range of the radio unit or the ground equipment has not received the answer.

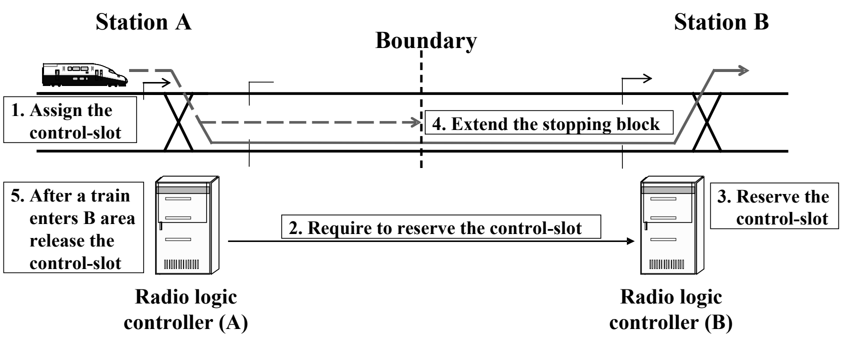

Figure 4: Administration of time slots (Handover).

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3.2 Administration of time slots

Because the covering area of a radio unit is limited, the logic controller administers the time slot of the train to continue the control of the train even in the boundary section of radio units. This function is generally called “handover”. The handover method is described in the following on condition that the boundary of radio units corresponds with that of radio logic controllers.
(1) When the on-board device is turned on at station A, the control-slot is assigned as described above.
(2) If the stopping block of the train which depends on the preceding train position corresponds with the boundary section of the station A and B, the radio logic controller at the station A requires the radio logic controller at the station B through the Gate-Way to reserve the control-slot.
(3) Then the radio logic controller at the station B reserves the control-slot that isn’t utilized at present.
(4) After the reservation of the control-slot, the radio logic controller extends the stopping block of the train to the outside of the block occupied by the precedent train.
(5) If the train controlled by the radio logic controller at the station A enters the area of the station B, the train comes to be controlled by the radio logic controller at the station B using the reserved control-slot. And the control-slot at the station A is released.

Actually the function of the radio logic controller in terms of handover is more complicated because the boundary of radio units doesn’t correspond with that of radio logic controllers.

4 Substitute block system

4.1 Substitute block operation

A substitute block operation is carried out in the following case.
(1) Break down of a track circuit between switch stations.
(2) Catenary trouble on one side.
(3) Blocking of a route one side by troubled train.
The cases of (2) and (3) have been dominant since the commencement of the Tohoku and Joetsu Shinkansen lines. Especially the substitute block operation using opposite line has frequently carried out because the regular block system can’t carry out the operation using opposite line.

4.2 Utilization of the developed system for substitute block operation

In the case of conventional substitute block system, there is no automatic train separation measure between neighboring stations. Therefore the maximum train speed is restricted below 110 km/h depending on attentiveness of a driver.

On the other hand, the train speed is automatically controlled in the developed system. And the developed system has the potential to raise the maximum train

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speed. The substitute block operation utilizing the developed system is carried out as follows.
(1) The substitute operation is ordered by the central headquarters.
(2) The commander confirms that there is no train between neighboring stations with the train count system using axle counters.
(3) The route for the substitute block is set.
(4) In a train, the train operation mode is switched to the substitute block operation by an operator.
(5) The operator runs the train under control of the developed system.

Developed system makes safer substitute block operation because of the less human errors. If communication error happens, the safety on the developed system would be secured because the interlocking system permits only one train to run between neighboring stations when the substitute operation carries out.

5 Trial tests and results

5.1 Test system's composition

The test equipment of the developed system was installed at Koriyama and Fukushima stations. The test equipment was composed of the following.
(1) Regular logic controller, which can set the substitute block route
(2) Track communication server
(3) Radio logic controller
(4) Radio unit
The Radio logic controllers at both stations were connected with ISDN at the speed of 64kbps.

5.2 Test results

The bit error rate of digital radio communication was below 10^{-6} and the quality of digital radio communication between ground equipment and trains was good enough for utilization. There was no difference between the location detected by the track circuits and detected by the position information from trains.

The test results show that there is no problem to adopt the developed system as a substitute block system.

6 Conclusion

An automatic train control system utilizing digital train radio for the Shinkansen has been developed. Applying the developed technology, it is expected that track circuits outside switch stations become unnecessary for train separation control. Trial tests have been carried out and the results are good enough for utilization. At the first application, we have decided to introduce the developed system as a substitute system which will realize safer substitute block operation.

In the future, the system will become major train protection system of the Shinkansen lines.

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