A New Signalling System for Automatic Block Signal between Stations Controlling through an IP Network

[1]R. Ishima, [1]Y. Fukuta, [1]M. Matsumoto, [2]N. Shimizu, [3]H. Soutome, [4]M. Mori
East Japan Railway Company, Saitama, Japan[1]; Daido Signal Co.,Ltd., Tokyo, Japan[2];
Hitachi, Ltd., Hitachinaka, Japan[3]; Toshiba Corp., Tokyo, Japan[4]

Abstract

This paper describes a new signalling system which controls signalling field devices of automatic block signal between stations through an IP network. The system improves the method of the system already installed to Ichikawaono station on the Musasino line in February 2007. The Logic Controller (LC), placed in a signal house, exchanges the command and feedback data with the Field Controller (FC), placed near each automatic block signal, through the Ethernet Passive Optical Network (E-PON). Following the command data, the FC electrically controls signalling field devices such as signals, track circuits, transponders of the Automatic Train Stop (i.e. Automatic Train Protection) system with Pattern (ATS-P), transponders of the S-type of ATS (ATS-S), and output relays. Only optical fiber cable requires between the LC and the FC. The system has high reliability because the LC, the FC, and the data paths of E-PON are all duplex. The system provides sufficient maintenance information through the IP network. The system can realize higher reliability, less wire-connection-work, less amount of cable, cost cutting, and faster troubleshooting. A prototype system was under evaluation on the Joban Rapid Service line between Mabashi and Kitakashiwa from August 2006 to January 2008. Evaluating the results of the field test, we conclude that the prototype system is technically suitable for signal control. We currently improve the prototype system for the better use of maintenance, construction, and troubleshooting toward future installation. We have planned the second field test of the improved prototype system starting from June 2008.

1. Introduction

Train services in the Tokyo metropolitan area must always be normal and stable. Signalling systems installed to the area require quite high reliability. Faster recovery to normal services is expected, even if a malfunction of the systems occurs and disrupts the train services.

In the conventional signalling system for automatic block signal between stations, signalling field devices such as signals, track circuits, transponders of the Automatic Train Stop (i.e. Automatic Train Protection) system with Pattern (ATS-P), transponders of the S-type of ATS (ATS-S) are distributed along the wayside with severe environment for computerized equipment. All the devices are simplex with low reliability. The maintenance information is insufficient, which may cause long recovery time in case of a signal malfunction.

East Japan Railway Company (JR East) installed a signalling system to the Chuo line between Tokyo and Takao (the Chuo-line system), where all control units are duplex and placed in a central signal house with good environment. The system, however, controls each signalling field device located along the wayside directly from the central signal house through enormous number of metal cables, which require high cost and much construction work. The cables are still simplex, while all control units are duplex.

In order to reduce the amount of the metal cables and to lighten engineers' duty of wire-connection-work, JR East developed a signalling system that controls the field devices in a station yard through an IP network. [1] It is the IP-NEtwork-based Signal Control System for a Station Yard (NESCS-SY). NESCS-SY was installed to Ichikawaono station on the Musashino line in February 2007, and has been in normal operation with no trouble. [2]

Improving the method of NESCS-SY and following the system configuration of the Chuo-line system, where the control equipment is centralized, we have developed a new signalling system for automatic block signal between stations controlling through an IP network in order to achieve higher reliability, less wire-connection-work, less amount of cable, cost cutting, and faster troubleshooting. It is the IP-NEtwork-based Signal Control System for Automatic Block Signal between stations. (NESCS-ABS)

2. System Configuration

2.1 Overview of NESCS-SY

Fig 1 shows the overview of NESCS-SY in which NESCS-ABS originates. NESCS-SY consists of the Field object Controlled Processor (FCP), the Field Controller (FC), and the Ethernet Passive Optical Network (E-PON). The FCP is placed in the signal house and connected with computerized interlocking equipment. Each signalling field device has the FC inside itself or in a signal box. NESCS-SY uses the E-PON as an IP network. The E-PON connects the FCP with the FCs, and transmits the data of IP protocol. The E-PON central unit is placed in the signal house. The E-PON branch unit is built in the FC.

The control process of NESCS-SY is as follows. The FCP converts the command information created by the computerized interlocking equipment into the IP-formatted command data, and sends it to the FCs through the E-PON. Each FC receives the IP-formatted command data, translates the data, and electrically controls the signalling field devices. Each FC also receives the feedback information from the signalling field devices, converts the information into the IP-formatted feedback data, and sends it to the FCP through the E-PON. The FCP receives the IP-formatted feedback data, converts it to the feedback information, and hand it to the computerized interlocking equipment.

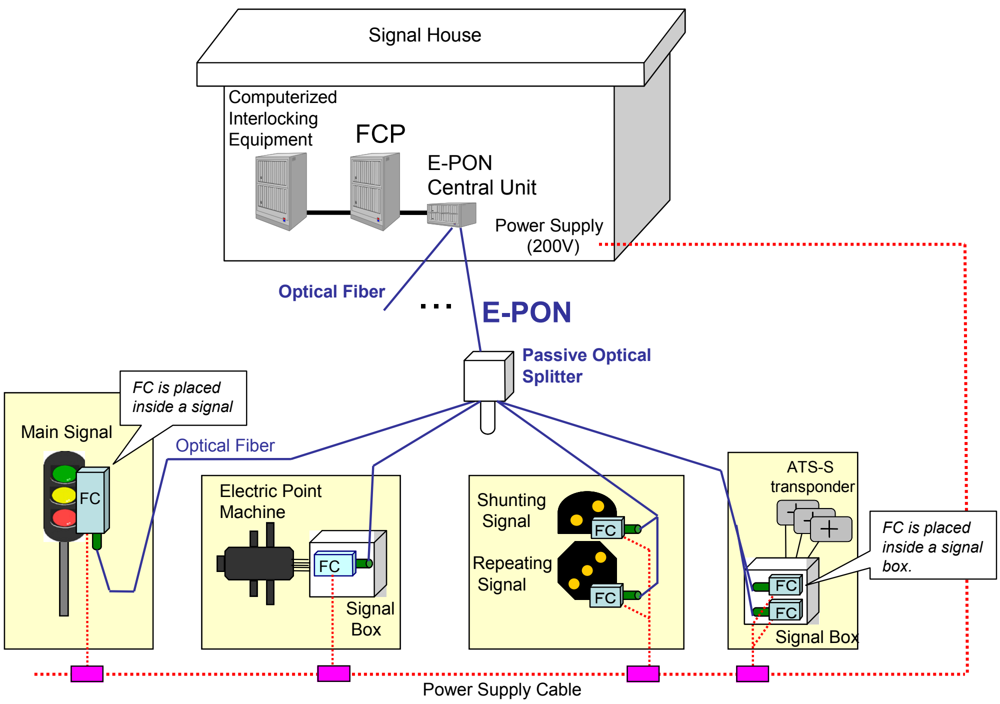


Fig 1: Overview of NESCS-SY

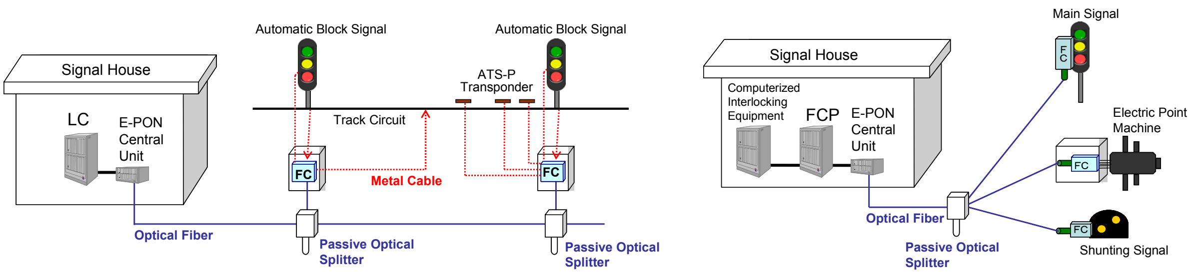
2.2 Fundamental Configuration of NESCS-ABS

Utilizing the method of NESCS-SY, we defined the fundamental configuration of NESCS-ABS as follows:

1) The Logic Controller (LC), which corresponds to the FCP of NESCS-SY, integrates several control logics of signalling field devices of automatic block signal between stations. The LC is placed in a signal house.

2) The Field Controller (FC), which corresponds to the FC of NESCS-SY, electrically controls the signalling field devices together because they are located near each automatic block signal. The FC is placed near an automatic block signal and connected with signalling field devices through metal cables. On the other hand, each signalling field device has the FC inside itself or in a signal box in NESCS-SY because signalling field devices are scattered in a station yard.

3) The E-PON is used as an IP network as used in NESCS-SY. The transmission procedure between the LC and the FCs is almost the same as the one between the FCP and the FCs in NESCS-SY.
Fig 2 shows the comparison of fundamental system configurations between NESCS-ABS and NESCS-SY



(a) NESCS-ABS (b) NESCS-SY

Fig 2: Comparison of fundamental system configurations between NESCS-ABS and NESCS-SY

2.3 Overview of NESCS-ABS

Fig 3 shows the system configuration of NESCS-ABS. The system consists of the LC, the FCs, E-PON, the Remote Monitoring and Controlling System (RMCS), and the Maintenance Terminal (MT).

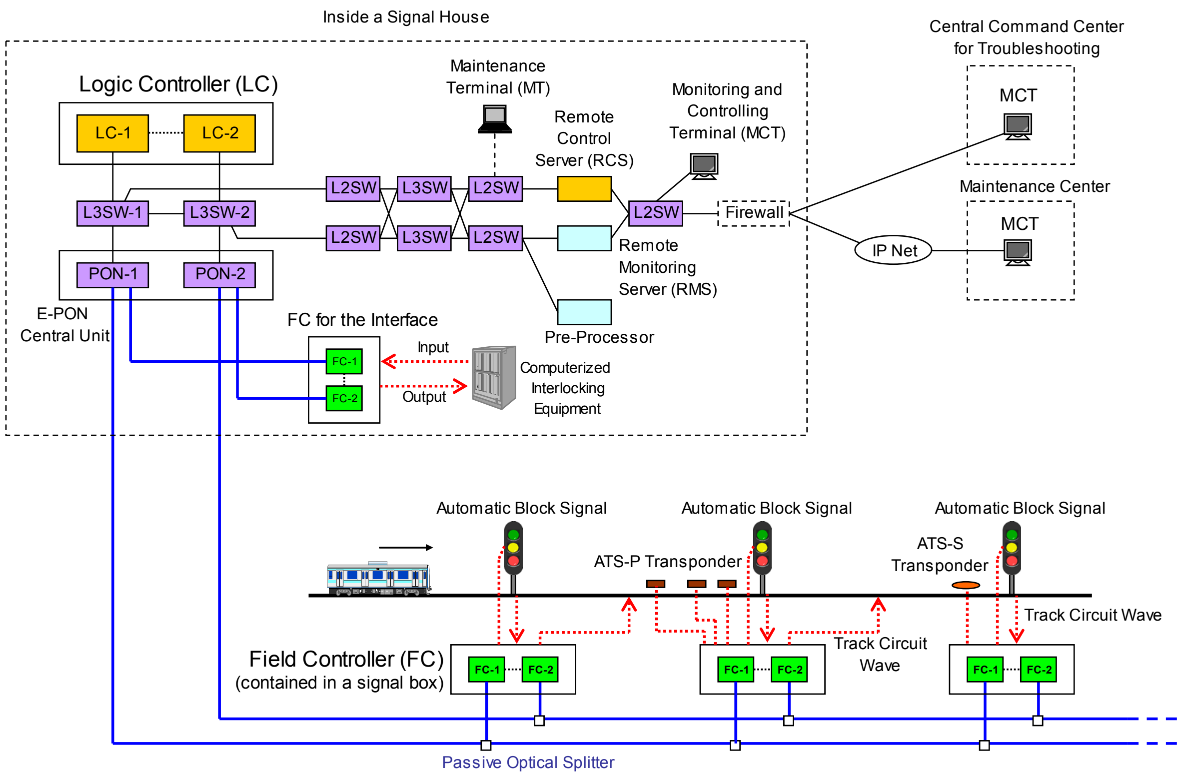


Fig 3: System configuration of NESCS-ABS

2.3.1 Logic Controller (LC)

The LC, placed in a signal house, has a new control logic which integrates the whole control logics of signalling field devices of automatic block signal. The LC is a duplex system which consists of fail-safe units. In the conventional signalling system, each signalling field device distributed along the wayside independently works and exchanges the limited information with each other, which results in the limited function of the system. With the integrated control logic, the system can handle several field devices of automatic block signals in one procedure and easily realize the stronger functional connection among those devices.

Under the process cycle of 200 ms, the LC decides the output information of automatic block signals, ATS-P, ATS-S, and output-relays, converts the output information into the IP-formatted command data, and sends it to the FCs through the E-PON. As a response of the command data, the LC receives the IP-formatted feedback data of train detection, ATS-P, and input-relays from the FCs through the E-PON, converts it into the feedback information, and utilizes it in order to decide the output information of next process cycle.

In order to control field signalling devices near the system boundary, the LC needs to exchange the information with the interlocking equipment or with the adjacent LC. The LC exchanges the information with the interlocking equipment through the FC for the interface. (see Fig 3) The LC also exchanges the information with the adjacent LC through another IP network which directly connects two LCs.

Two suppliers concurrently develop the LC under the same requirement specification by JR East. One supplier creates the LC using the same hardware of the FCP of NESCS-SY. The other supplier creates the LC improving the hardware of the computerized interlocking equipment. Fig 4 shows the overview of the two prototypes of the LC.

Fig 4: Overview of the two prototype of the LC

2.3.2 Field Controller (FC)

The FC, placed near each automatic block signal, electrically controls signalling field devices together. The FC is a duplex system which consists of fail-safe units. The FC contains a logic unit, a system management unit, an E-PON branch unit, and control units of each signalling field device. One fail-safe CPU built in the logic unit controls all the units of the FC. In addition to the FC for automatic block signal, we have developed another type of the FC for the interface to exchange the information with the interlocking equipment. (see Fig 3)

Under the process cycle of 200 ms, each FC receives the IP-formatted command data of automatic block signals, ATS-P, ATS-S, and output-relays from the LC through the E-PON, translates the data, and electrically controls the signalling field devices through metal cables. Each FC also obtains the information on train detection and status of signal devices electrically, converts the information into the IP-formatted feedback data, and sends it to the LC through the E-PON.

The track circuit of NESCS-ABS is a non-insulated-joint type. An FC transmits the track circuit wave and put it into the rail of the central point of a block. The same FC and another FC located at both ends of the block receive the track circuit wave. The modulation type of the track circuit wave is AM (Amplitude Modulation), the same modulation type already installed to the tunnel section of the Sobu-Yokosuka line.

Since the FC must endure the severe environment along the wayside, the signal box which contains the FC (FC Box) has a special structure for the environment such as temperature, vibration, and lightening surge. The FC Box has airtight structure to prevent dust from entering. The requirement specification of the maximum of internal temperature of the FC Box is 60 °C. The FC Box has a duplex fan which creates internal air flow in order to uniform the internal temperature and to radiate heat outside through a heat-radiation-fin. The FC Box connects with metal cables by connector-units to reduce wire-connection-work. Fig 5 shows the overview of the prototype of the FC and the FC Box.

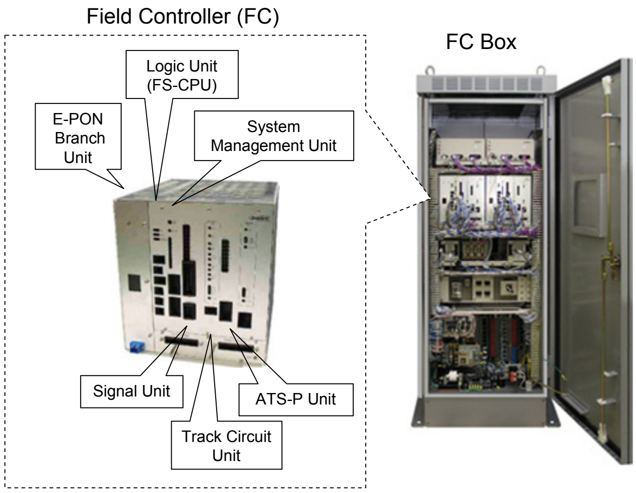


Fig 5: Overview of the prototype of the FC

2.3.3 E-PON

NESCS-ABS exchanges data of IP protocol between the LC and the FCs through the E-PON as NESCS-SY does between the FCP and the FCs. The data paths of the E-PON are duplex. The E-PON access unit, placed in the signal house, connects with the LC. The E-PON branch unit is built in each FC.

The E-PON is suitable for NESCS-SY and NESCS-ABS because the E-PON does not rely on electrical power to transport data from the central unit to the branch one. The data of optical signal is simply broadcast, branching off at the passive optical splitter. The E-PON central and branch units are commercial products for general use of network communication. They are not specially developed for the use of NESCS-SY or NESCS-ABS.

While NESCS-SY uses symmetric passive optical splitters to divide optical signal into eight, sixteen, or thirty-two, applying to the signalling field devices scattered in a station yard, NESCS-ABS uses asymmetric passive optical splitters at a two-eight ratio because optical fiber cables are placed along the wayside, branching off at each automatic block signal.(See Fig 2) One optical path can connect with up to four FCs under the limitation by the level loss of optical signal at the optical splitter. Since only several number of optical fiber cables are placed between the LC and the FCs, NESCS-ABS accomplishes less construction work with cost cutting, compared to the Chuo-line system where enormous amount of metal cables are placed between a signal house and signalling field devices.

2.3.4 Remote Monitoring and Controlling System (RMCS)

NESCS-ABS uses the RMCS as used in NESCS-SY. The RMCS has client-server architecture and consists of the Remote Monitoring Server (RMS), the Remote Controlling Server (RCS), and the Monitoring and Controlling Terminal (MCT). The RMCS connects with the IP network of E-PON in the signal house.

The RMS supervises the whole equipment connected with IP network and stores the log data of the LC and the FCs. The RCS remotely controls the LC and the FCs with several control commands such as the system reset. The MCT is a user-interface terminal for the access to the RMS and the RCS. Apart from the signal house, other MCTs are also placed at the central command center for troubleshooting and the maintenance center. They can access RMS and RCS by connecting with the IP network in the signal house through a firewall. The central command center and the maintenance center can remotely extract sufficient detailed information with the MCT, which may contribute to the faster troubleshooting. The central command center can also remotely operate the several control commands of the LC and the FC in case of troubleshooting.

2.3.5 Maintenance Terminal (MT)

NESCS-ABS uses the Maintenance Terminal (MT) as used in NESCS-SY. Using the MT, a maintenance engineer can download the system software and data into the LC or the FC, change the system software between the current version and the stored one for the test, and stop and start the LC or the FC. The MT temporarily connects with the IP network only in the signal house to access the LC or the FC in case of maintenance. The maintenance center strictly regulates the operation of the MT.

2.3.6 Supporting Software for the Creation of the System Data.

We have also developed the supporting software for the creation of the system data in order to support system designers' work. The software helps a system designer make the constant data list of the system definition, and then automatically produces the network definition list which assigns IP addresses to all the devices in NESCS-ABS.

2.4 Safety and Reliability of the Transmission between the LC and the FC

The basic features of the safety and reliability of the transmission between the FCP and the FC of NESCS-SY [3, 4] is applied to the transmission between the LC and the FC of NESCS-ABS. Both the LC and the FC consist of fail-safe units, which ensures the safety of the communication between them. Fig 6 shows the transmission paths between the LC and the FC. With double paths of the E-PON and the routing technique, NESCS-ABS has four data paths for the transmission between the LC and the FC. Since even one data path can ensure the normal operation of the system, NESCS-ABS has high reliability.

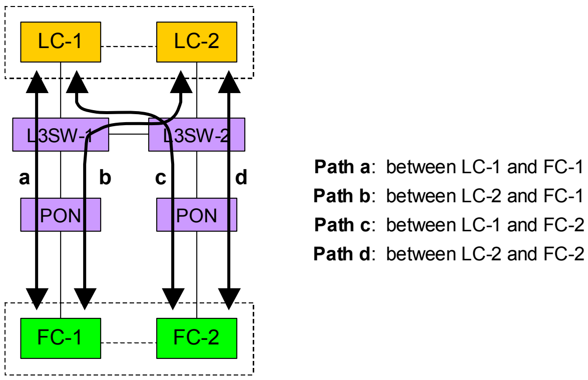


Fig 6: Transmission Paths between the LC and the FC

The data transmission between the LC and the FC uses UDP (User Datagram Protocol) and utilizes the following five techniques to ensure the safety of the signal control.

1) The transmitting equipment adds a sequence number to the data. The receiving equipment checks the sequence number added to the data.

2) The transmitting equipment adds an ID code which defines the source and the destination addresses, to the data. The receiving equipment checks the validity of the ID code.

3) The transmitting equipment adds a Cyclic Redundancy Check (CRC) to the data separately from the Frame Check Sequence of the Ethernet frame. The receiving equipment checks the CRC.

4) The LC watches the time delay of the feedback data from the FC. If the LC does not receive the feedback data within 200ms after receiving the former feedback data, the LC adds a time-out flag to the command data and sends it to the FC. If the FC finds a time-out flag in the command data, the FC does not use the command data and makes its outputs safe-side values.

5) The FC watches the time delay of the command data from the LC. If the FC does not receive the command data within 250ms after receiving the former command data, the FC makes its outputs safe-side values.

2.5 Reliability of the System

NESCS-ABS has high reliability because the LC, the FC, and the data paths of E-PON are all duplex. It has better reliability than the conventional signalling system where the simplex units of ATS-P are distributed along the wayside. It has even better reliability than the Chuo-line system where the metal cables between a central signal house and field devices are still simplex although all control units are duplex under good environment in a signal house.

2.6 Project Team for the Development of the System

The project team for the development of NESCS-ABS consists of JR East and four suppliers, as shown in Table 1. JR East makes the requirement specification of NESCS-ABS. JR East and four suppliers jointly decide the detailed functional specifications and the interface specifications. All the interface specifications are open to the four suppliers. JR East has a role to manage the interface specifications.

Product	Supplier
Logic Controller (LC)	Supplier A, Supplier B
Field Controller (FC)	Supplier C
Network Equipment such as E-PON, L3SW, and L2SW	Supplier D (only providing commercial products)
Remote Monitoring Server (RMS)	Supplier D
Remote Controlling Server (RCS)	Supplier A
Monitoring and Controlling Terminal (MCT)	Supplier C

Table 1: List of the project team

3. Test

3.1 Overview of the Field Test

In order to evaluate the functional performance of control and transmission and to evaluate the reliability and the environment-resistant performance under the actual railway field over the long run, we put a prototype system of NESCS-ABS into the Joban Rapid Service line between Mabashi and Kitakashiwa from August 2006 to January 2008 for the field test. We started the environment-resistant performance test from August 2006 with one FC Box, followed by the functional performance test with the whole prototype system from November 2006. Fig 7 shows the system configuration of the field test on the Joban Rapid Service line.

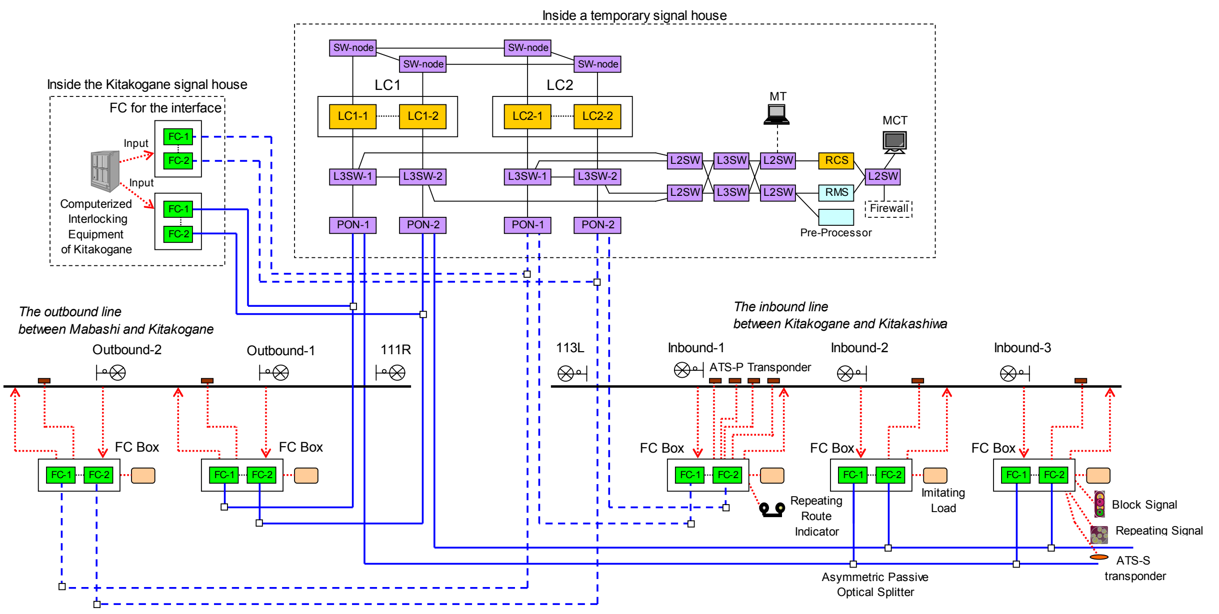


Fig 7: System Configuration of the Field Test on the Joban Rapid Service line

Five FC Boxes are placed near the five automatic block signals respectively. Two FC for the interface are placed to obtain the information on the signals ahead belonging to the station yard of Kitakogane from the Kitakogane computerized interlocking equipment. Two LCs are placed in a temporary signal house. Supplier-A and Supplier-B provide LC1 and LC2, respectively.(see Fig 4) LC1 controls three automatic block signals of Outbound-1, Inbound-2, Inbound-3, and LC2 controls two automatic block signals of Outbound-2, Inbound-1. LC1 and LC2 regard each other as the adjacent LC. They exchange required information with each other through another IP network to control signalling field device around system boundary. The non-insulated-joint-type track circuits of the FCs are installed to the actual rail with no interference in existing AC track circuits. The ATS-P transponders are also placed into the actual rail in order to obtain ATS-P codes from running trains.

In order to evaluate the NESCS-ABS system by comparing the two control results of the NESCS-ABS prototype system and the existing signalling system at each running train, we prepare the comparing equipment which stores the log data of the existing signalling system. The number of running trains on the Joban Rapid Service line of the field test section is around two hundreds in each direction.

3.2 Results of the Field Test

3.2.1 Evaluation of the Functional Performance

During the field test from November 2006 to January 2008, when the whole system was in operation, we compared the result data controlled by NESCS-ABS with the one by the existing system at each running train on the Joban Rapid Service line of the field test section. With about 200 trains running a day, we verified that all the result data controlled by NESCS-ABS corresponded with the one by the existing system except in the following two cases. The one case is caused by the difference between two track circuit systems. While the existing AC track circuit with insulated joints detects a train with the response time of a track relay, the non-insulated-joint-type track circuit of NESCS-ABS detects a train with the process time of 500ms in entering or of 1000ms in departing. The other case is caused by the difference between two specifications of the signal control using ATS-P code from running trains. Since both of the two cases have clear causes, we verified that the control logic of NESCS-ABS is suitable for signal control. We also verified that the basic functions of the RMCS such as the supervision of equipment, the output of system warning, and the extraction of the log data were in normal operation and is appropriate to the monitoring and maintenance of the system.

3.2.2 Evaluation of the Reliability and the Environment-resistant Performance

During the field test, no environment-oriented malfunction occurred in the prototype system. Network equipment such as E-PON central and branch units, L3 switches, L2 switches, and switching nodes kept in normal operation with no transmission error.

A certain number of malfunctions caused by such as software bug, hardware design defect, and mismanagement of the interface had occurred in the initial stage of the field test. After we clarified the cause of the malfunctions and improved the system, the prototype system kept in normal operation and there was no malfunction with the cause unclear at the end of the field test.

3.2.3 Result of the Field Test concerning the Internal Temperature of the FC

In order to verify that the requirement specification of the maximum of internal temperature of the FC Box, 60 °C, is satisfied, we measured the internal temperature of the FC Box from August to October 2006 during the environment-resistant performance test with one FC Box. Fig 8 shows the result of the internal temperature of the FC. The maximum temperature was recorded on Sep 5th and the graph in Fig 8 displays the internal temperature from Sep 2nd to Sep 8th including Sep 5th. The temperatures of all six measuring points are almost the same because the duplex fan of FC Box with airtight structure creates internal air flow and uniforms the internal temperature. The change of temperature during a day varied because of the climate. The maximum temperature of 53.8 °C was recorded on Sep 5th when the outside temperature was 34.8 °C. The correlation between the internal temperature of FC Box and the outside temperature depends on the climate. Since the climate on Sep 5th was clear with almost no wind, the difference between the internal and outside temperature should be maximum. Therefore even if the outside temperature reaches 40 °C, the internal temperature of FC Box can be under 60 °C.

Considering the one-side fault of a duplex fan, we measured the internal temperature of the FC Box when only one-side fan was in operation at a testing site. The internal temperature of 47.5 °C was recorded when the outside temperature was 28.5 °C. Therefore even if the one-side fault of a duplex fan occurs and the outside temperature reaches 40 °C, the internal temperature can keep under 60 °C.

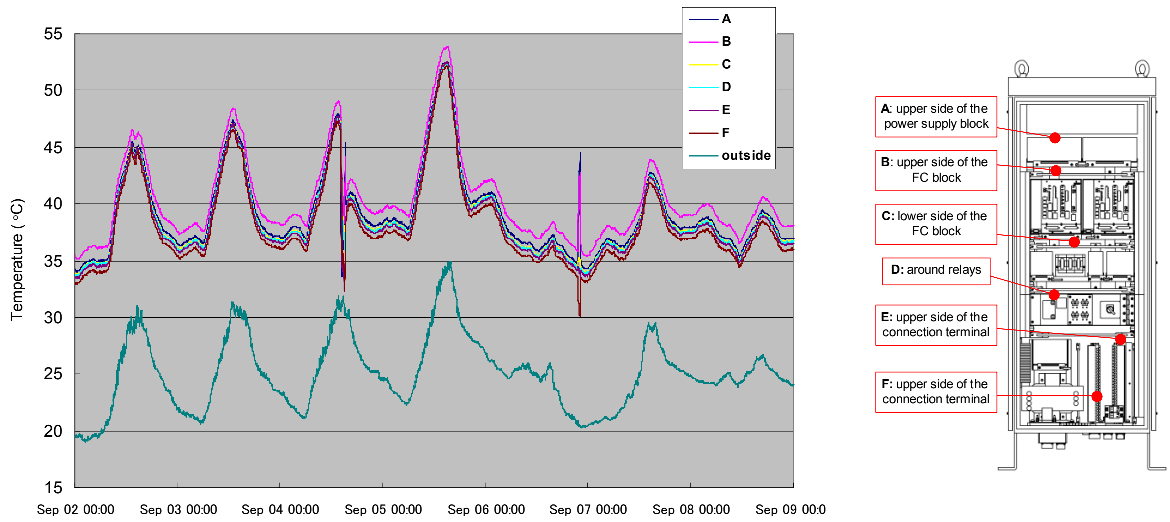


Fig 8: Internal Temperature of the FC during summer

3.3 Environment-resistant Test

The FC Box must pass required environment-resistant tests because it must endure the severe environment along the wayside. We defined the minimum values of each environmental condition which the FC Box must pass, referring IEC (International Electrotechnical Commission) and JIS (Japanese Industrial Standard) applied to conventional signal field devices. We designed the FC to cope with those conditions. Table 2 shows the main environmental conditions of the FC. Concerning the condition of EMC, we refer to IEC 62236-4, applied to signalling and telecommunication apparatus which is installed in the railway environment. As for Impulse surge voltage, we defined 30kV for power port and 20kV for I/O port, the same conditions used in NESCS-SY. We performed the environment-resistant tests for the FC Box based on the defined environmental conditions at testing sites. The FC has passed all the environment-resistant tests and satisfied those environmental conditions.

Internal temperature	-10 to 60 °C
Vibration	10 to 500 Hz (over 1G) by JIS E3014 type-2
Water-proof	JIS E3017 R2
Electro Magnetic Compatibility (EMC)	IEC 62236-1, 4
Impulse surge voltage	30kV for power port
	20kV for I/O port

Table 2: Main environmental conditions of the FC

3.4 Total Evaluation of the Test

Evaluating the results of the field tests and environment-resistant tests, we technically verified that NESCS-ABS is suitable for signal control. We also judged that the prototype system needed to be improved from the view of maintenance, construction, and troubleshooting in consideration of future installation. We have decided to improve the prototype system.

4. Improvement of the System toward Installation

4.1 Improvement features

We have started improving the prototype system from the view of maintenance, construction, and troubleshooting, toward future installation. We have planned the second field test for the improved prototype system starting from June 2008. The improvement features are as follows

1) Improvement of the FC Box
In the prototype system, we tried to make the FC Box small considering the limited space along the wayside for the construction of the FC Box. As a result, the high density of the electric parts in the FC Box may make the maintenance work difficult. For better maintenance, we make the size of the FC Box larger and rearrange the placement of the electrical parts.

2) Development of the FC for the system boundary
The FC for the interface was already developed to exchange the information with the interlocking equipment. It has, however, only the relay interface. In order to adjust the various types of system interfaces, we develops the FC for the system boundary which has the serial interface, the Ethernet interface, and the interface for the transmission between encoders of the existing ATS-P system.

3) Improvement of the acquisition of monitoring information
For the support of troubleshooting, we improve the acquisition of monitoring information to get detailed information of the location of the signalling trouble. In order for maintenance engineers to operate the mobile MCT and to check the required information at the FC Box during troubleshooting, we also improve the system to provide monitoring information at the FC Box through an optical fiber for maintenance.

4) Change of the modulation type of the non-insulated-joint type track circuit wave
In the prototype system, we applied AM modulation for the non-insulated-joint type track circuit wave. Since the track circuit wave must endure the electromagnetic noise from running trains, we change the modulation type of the track circuit wave into the MSK (Minimum Shift Keying) type toward future installation.

4.2 Plan of future installation

JR East draws up a project which simplifies and integrates signalling systems in the Tokyo metropolitan area within a radius of about 50 km in order to minimize signal malfunctions and to keep normal train service. JR East plans to install NESCS-ABS under the project.

5. Conclusion

This paper describes the overview of NESCS-ABS and the result of the field tests. We technically verified that NESCS-ABS is suitable for signal control. We currently improve the prototype system of NESCS-ABS from the view of maintenance, construction, and troubleshooting, toward future installation. We hope that the improvement of the prototype system and the second field test for the improved system from June 2008 will succeed. We believe that NESCS-ABS could activate the innovation of the signalling system for automatic block signal between stations.

References

[1] Y. Hirano, Takashi. Kato, T. Kunifuji, T. Hattori, Tamotsu Kato, “Development of Railway Signalling System Based on Network Technology,” IEEE SMC, Oct.2005.

[2] “Installation of the First Network Signal Control System,” press release by East Japan Railway Company, Nov 7, 2006 (URL: http://www.jreast.co.jp/e/press/20061102/index.html).

[3] H. Sugahara, T. Kunifuji, T. Hattori, Y. Hirano, Y. Fukuta, M. Matsumoto, “Assurance Technologies for Signal Control System by Optical LAN,” IEEE Assurance Conference, July.2006.

[4] Y. Fukuta, G. Kogure, T. Kunifuji, H. Sugahara, R. Ishima, M. Matsumoto, “Novel Railway Signal Control System Based on the Internet Technology and Its Distributed Control Architecture,” IEEE ISADS, March.2007.