Advanced Signaling Systems Based on Transmission Technology for High-density Traffic

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OVERVIEW: We have developed signaling systems to increase the transportation capacity and ease rush-hour traffic in metropolitan areas. This is achieved by using an on-board controller that generates a parabolic braking pattern according to the limit of movement authority (LMA) transmitted from digital field controllers. One system is called "the digital ATC[1]" (D-ATC) and it is now being tested for commercial operation. The field controllers calculate the LMA by using a track circuit unit and transmit digital signals to track circuits. The on-board controller generates a parabolic braking pattern according to the LMA and recognizes its own location. The other system, ATACS*[2], is a radio-communication-based signaling system that makes full use of radio communication technologies. An on-board controller in this system recognizes the location of trains without using track circuits. Field controllers track the location of trains and calculate the LMA based on the train location obtained through radio transmission. The on-board controller generates a brake pattern according to the LMA received from the field controllers. This system enables moving-block signaling for high-density traffic control. We are planning to develop advanced signaling systems based on these systems.*

INTRODUCTION

THE transportation systems of the metropolitan areas in Japan have been upgraded to prevent bottlenecks during the peak of business activity. Recently, people in Japan have been taking greater interest in the quality of transportation services and have shown great concern with the living environment.

The railway system in Japan is the main public transportation system because it is less harmful to the environment and safer than automobiles or airplanes. Although the transportation capacity in the metropolitan areas of Japan has been improved, rush-hour crowdedness remains a serious problem because of an increasing rate, up to the early 1990's, of population growth in metropolitan areas. Thus, improving the transportation capacity and quality of transportation services is very important.

This paper demonstrates that D-ATC can be effectively used for high-density traffic, while ATACS, a radio-communication-based signaling system, is not only suitable for high-density traffic but also cost-efficient due to the use of radio communication technologies.

DEVELOPMENT OF TRANSMISSION-BASED SIGNALING SYSTEMS

Developing new signaling systems to enable trains to run at a higher speed and in higher density traffic is important if we are to increase the transportation capacities of metropolitan railways and Shinkansen lines in Japan.

Conventional signaling systems mainly track trains by using track circuits. These systems send permitted speed signals to trains through way-side signals and analog transmission track circuits. Recently, development has begun to improve conventional signaling systems in order to increase the transportation capacity and to make field and on-board controllers cooperate by using the latest electronics and digital communication technologies. A basic control method is to recognize the LMA of each train at field controllers, transmit these data to the trains, and generate an optimum brake pattern according to

*1: ATC (automatic train control) means ATP (automatic train protection) in this paper.
*2: ATACS: advanced train administration and communications system

the received LMA and each train's performance at the on-board controller.

The D-ATC system we developed is based on this method. Track circuits are used as digital transmission media in this system. While in conventional systems the track circuits must be broken into short circuits to cut the headway, which also increases the cost, such shortening of track circuits is not needed in this system because brake patterns are generated at an on-board controller according to the LMA. Thus, the system enables reducing equipment and maintenance costs.

Another such system is a radio-communication-based signaling system, which renders track circuits unnecessary. Field and on-board controllers closely cooperate through duplex digital radio transmission in this system. This system is an on-board controller-driven system and it can reduce construction and maintenance costs as well as ground-side equipment costs. Further, this system can rapidly act according to circumstances in case of foul weather or accidents. ATACS is such a system in Japan, and East Japan Railway Company is managing its development.

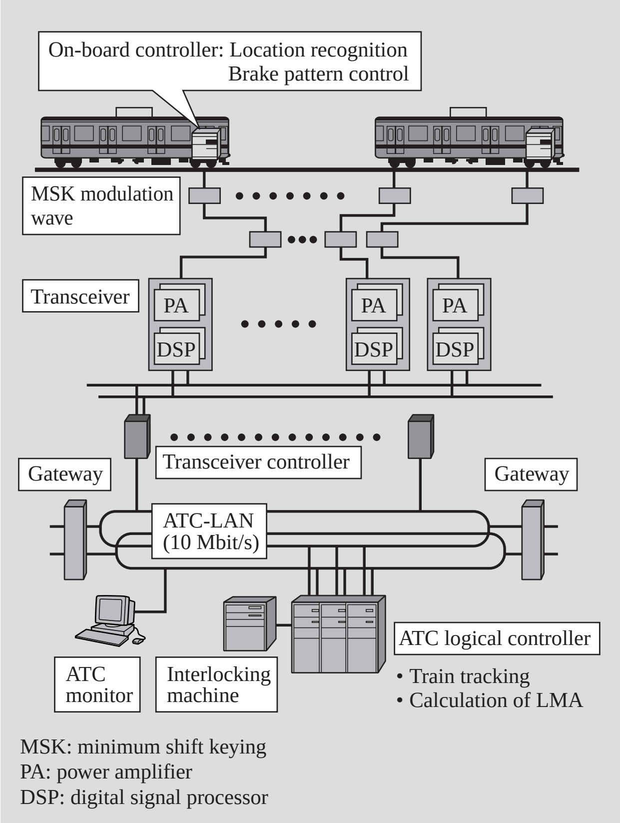

Fig. 1— Digital ATC.
Digital ATC is effective in shortening headway and travel time while decreasing the number of ground facilities.

D-ATC SYSTEM

Outline of D-ATC and Its Control Method

In D-ATC, digital signaling codes calculated from the location of each train and the route setting condition are transmitted to each train through track circuits, instead of conventional analog signals (mixed tone signal) transmitted through track circuits as permitted speed signals. The on-board controller that receives the LMA generates a parabolic braking pattern according to the LMA and carries out braking control.

This control method enables optimum stopping control and cuts the headway and running time, because there is no loss of time due to stopping control as in conventional decelerating control by a stepbraking pattern according to track circuits, and an optimum parabolic braking pattern can be generated autonomously according to each train's performance.

Field control systems are decentralized and connected over a network. Each logic part in the controllers is autonomous, which makes it possible to construct this system step-by-step. The D-ATC system is based on such an autonomous decentralized-control architecture.

Field Controllers

Field controllers are installed at each interlocking station and an ATC logic controller acts as s master system. The ATC logic controller is constructed with a triplex system architecture; it tracks each train, calculates the LMA from each train's location and route setting conditions, and generates a coded ATC message.

Transceivers modulate and transmit coded ATC signals generated by the ATC logic controller and receive and transmit train recognition signals. Digital signal processors (DSPs) perform modulation, demodulation, and level setting operations. The transceivers are constructed with power amplifiers (PAs) in a double-redundancy architecture to amplify the transmission power. The operating transceiver in double functioning system is automatically changed by a transceiver controller.

Messages about train tracking or the state of interlocking between neighboring ATC logic controllers are transmitted through gateway machines. The ATC logic controller and transceiver controllers, etc. are connected over an ATC-LAN with a throughput of 10 Mbps and maximum transmission distance of 40 km. With this architecture, we have reduced the number of devices and cut the construction costs (see Fig. 1).

We have also developed an ATC monitor that can

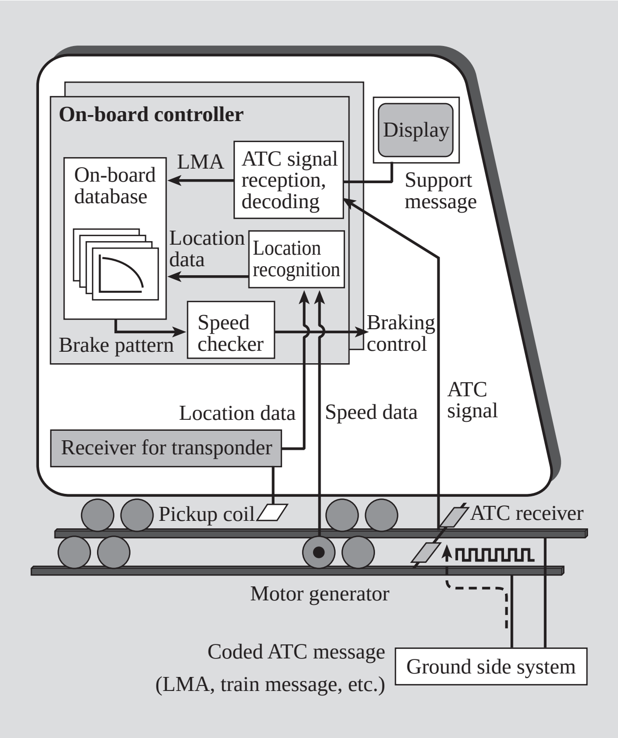

Fig. 2— On-board System in Digital ATC.
The on-board system performs pattern generation and braking control corresponding to the position of stopping track circuits.

maintain data about the power level of track circuits for one year, show the trend or real-time diagrams of these data, and perform preventive conservation by monitoring changes in these data. Further, we have supplied portable analyzers to adjust the power level of track circuits and analyze coded ATC messages to improve maintenance.

On-board Controller

The main characteristic of the D-ATC system is that trains recognize their locations and control their speed by themselves according to the LMA from field controllers.

Brake patterns previously generated by all trains over different line conditions are stored in an on-board controller for justifying the integrity of their patterns in advance and improving the speed of pattern searching. The on-board controller exercises stopping control by generating a brake pattern from its position-recognition data and the received track circuit number to stop the train.

Further, we have developed functions that (1) improve the riding quality with the use of light brakes, (2) show the train location and the time to start activating the brakes, to support the train crew, and (3) improve train maintenance by using powerful diagnostic equipment.

A receiver and a speed checker separated conventionally have been integrated to improve the hardware architecture, which has enabled miniaturizing the on-board controller and improved its cost performance (see Fig. 2).

The controller of the receiver we developed can process both D-ATC and conventional ATC signals. Because switching between D-ATC and conventional ATC processing is performed autonomously, the transference to D-ATC can be accomplished easily.

RADIO-COMMUNICATION-BASED SIGNALING SYSTEM AND ATACS

Outline of Radio-communication-based Signaling System

The main target of a radio-communication-based signaling system is generally to get rid of safety control based on track circuits. Its basic function is to recognize the location of the train at the on-board controller, transmit this information to a field controller through radio communication, track all the trains with these data at the field controller, and transmit the LMA from the field controller to the train.

This system is an on-board controller-driven system. The on-board controller has the following functions: (1) to recognize the location of trains as in D-ATC, (2) to communicate with field controllers, (3) to generate brake patterns according to continuously changing LMA, and (4) to cope with problems in communication or position recognition.

The field receivers in the system must have train tracking function to track the location of trains by using train location recognition data instead of track circuits. The system enables moving-block control because train location data are point data and do not occupy track circuits. Field controllers must track trains by controlling the hand-over in radio communication equipment such as a cellular phone because one piece of ground-side radio equipment cannot cover a long distance. This method enables ground-side equipment track and communicate with trains over the whole line.

This radio-communication-based signaling system is an advanced system that makes field controllers and trains cooperate through duplex radio communication.

Development of Radio-communication-based Signaling Systems and ATACS

Different radio-communication-based signaling systems are now being developed in Japan and abroad. European Rail Traffic Management System (ERTMS)

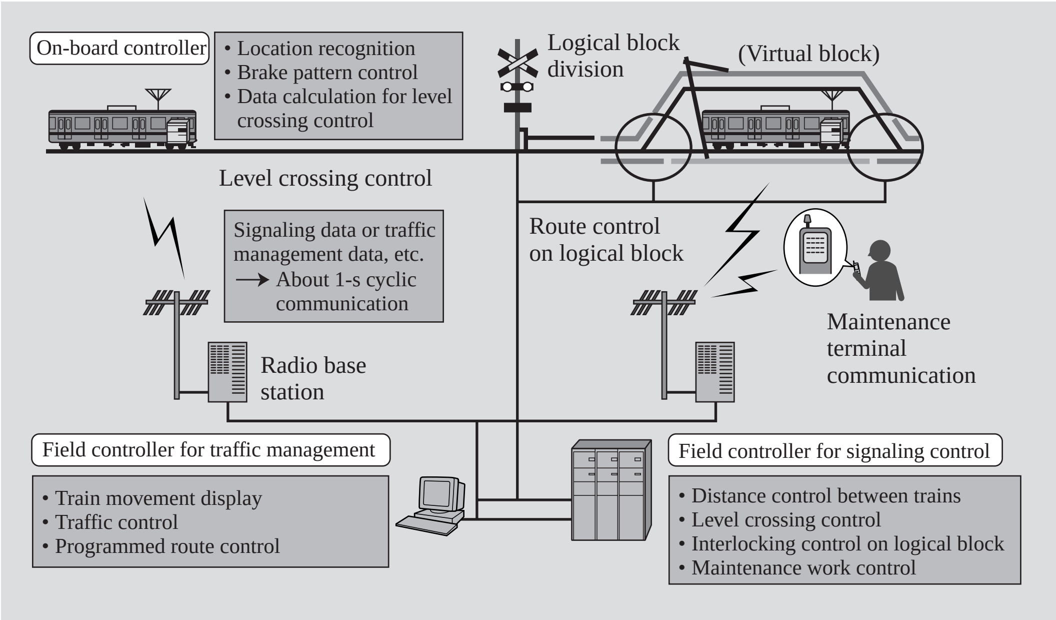

Fig. 3— ATACS.
ATACS performs basic system control using on-board location recognition and radio signal communications without the need for track circuits. It also provides advanced level-crossing control functions and makes maintenance work safer.

to be driven by European Union (EU) is a principal system under development. The ERTMS project also aims at decreasing system cost and unifying signaling systems, thereby resolving the inconvenience of trains being run by different signaling systems between member states of the European Union. The New York City Transit (NYCT) Authority is now implementing a radio-communication-based system for its subway system and the San Francisco Bay Area Rapid Transit (BART) District Authority is also developing a similar system.

In Japan, Railway Technical Research Institute was developing the computer and radio aided train control system (CARAT) from 1989 to 1993, and now the East Japan Railway Company manages the development of ATACS to advance CARAT.

In addition to controlling the distance between trains, field controllers of ATACS have the following functions: (1) level crossing control taking into account the location and speed of trains, (2) interlocking control by virtual block data converted from location recognition data received from trains, (3) upgrading the safety of maintenance by making use of duplex radio communication, (4) preparing communication bits for notifying obstruction or cause of temporal speed restriction to each train, etc (see Fig. 3).

The basic function of the on-board controller is to recognize its own location from transponders and motor generators, receive the LMA from field controllers, continuously generate a brake pattern according to the LMA by the moving block control method, and control brakes as required. Further, the on-board controller calculates the distance location to run ahead after a predetermined period according to the speed and faculty for level crossing control. The field controllers control level crossing signals by using data transmitted from the train (see Fig. 4).

Hitachi, Ltd. has developed a test system of field and on-board controllers and supported running tests on the Senseki line from September, 2000 to February,

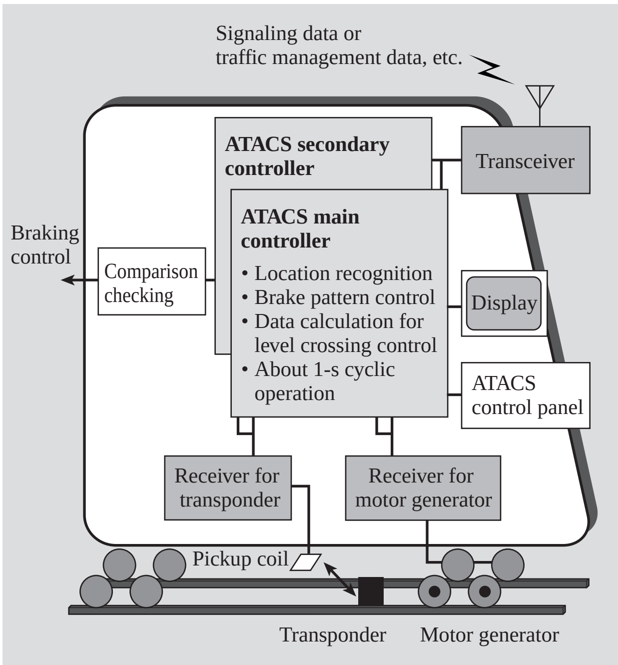

Fig. 4— On-board System in ATACS.
The on-board system performs basic control functions such as location recognition and brake pattern control and generates information for use in level-crossing control.

2001 under the management of the East Japan Railway Company.

The field controllers were constructed in the way of the triplex-redundancy fail-safe computer with 2-out-of-3 logic parts developed earlier for electronic interlocking equipment. We obtained a cyclic processing of approximately 1 s and verified the system performance in the test runs. The on-board controller demonstrated cyclic operating performance of approximately 1 s due to the use of double-redundancy fail-safe computers with output-comparison checking logic developed previously for conventional ATC and adopted for on-board controllers for Shinkansen. The performance of the on-board controllers as found by the test runs, was good. The field and on-board controllers have been developed by modifying software and a combining hardware developed earlier for interlocking machines and on-board controllers for conventional ATC systems.

CONCLUSIONS

We have developed a track-circuit-based D-ATC system and are developing a radio-communication-based signaling system (ATACS in Japan) as next-generation signaling systems.

As a railway maker, Hitachi, Ltd. has developed effective signaling systems. We will promote the development of new railway systems to improve passenger services and reduce life-cycle costs by making field and on-board controllers cooperate through the use of digital information processing and telecommunication technologies.

REFERENCES

(1) M. Matsumoto, "On-board Autonomous Decentralized Train Control System," *Tran. IEE of Japan*, Vol. **121**, No. 2 (Feb. 2001).

(2) M. Matsumoto et al., "The New ATC System with an Autonomous Speed Control with On-board Equipment," Proceedings of ISADS2001, Dallas USA, pp. 235-238 (Mar. 2001).

(3) H. Yamamoto et al., "Field Test of the Intelligent Speed Control by CARAT," *RTRI Report* Vol. **10**, No. 11, pp. 23-28 (1996).

(4) T. Kobayashi et al., "ATACS (Advanced Train Administration and Communications System)," *Proceedings of COMPRAIL 96*, Vol.**2**, pp. 199-205 (1996).

(5) T. Kobayashi et al., "Advanced Train Administration and Communications System Based on ADS Technologies," Proceedings of ISADS99, pp. 388-391 (1999).

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