# Railway Technology Today 8 *(Edited by Kanji Wako)*

# *Signalling Systems for Safe Railway Transport*

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## Introduction

Trains could not run safely without signalling devices. This article looks at four tools that ensure railway safety in Japan: block systems, train control systems, train traffic control systems, and wireless communications devices.

## Block Systems

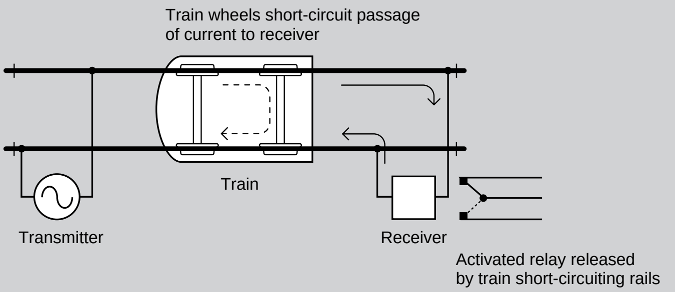
### Automatic block system

Braking distance—the distance needed to come to a complete halt after brakes are applied—is longer for trains than it is for road vehicles. Consequently, only one train can occupy a specific section of track at one time. Such a section of track is called a block. Track circuits are used to determine whether a train is in a specific block.

Figure 1 shows how the rails form part of an electric circuit (track circuit). When the train's wheels pass a certain point, they cause a short circuit, preventing electric current from proceeding further. This makes it possible to detect a train in a block.

An automatic block system uses the track circuit to automatically detect trains in blocks and to control the signals for each block. All double-tracked sections in Japan use the automatic block system. As Figure 2a shows, there are basically three signal aspects: red, meaning stop immediately before entering the next track section occupied by an ahead train; yellow, meaning proceed with caution at a speed no greater than 45 km/h (55 km/h or faster is permitted on some sections) as far as the signal, and green, meaning the next track section is clear and the train can enter that section at the maximum speed. In heavily used sections, two other signal aspects are also used (Fig. 2b): two yellow lights (restricted speed), and one yellow and one green light (reduced speed).

**Figure 1 General Principles of Track Circuit**




### Other block systems

In addition to the automatic block system, a number of other block systems are used on single tracks. In many cases, a track circuit system or an electronic block system (electronic coding verification system) is used. Both are semi-automatic block systems.

The track circuit system controls train movement in the blocks between stations, and involves interlocking signal levers at

**Figure 2 Automatic Block Signalling System**

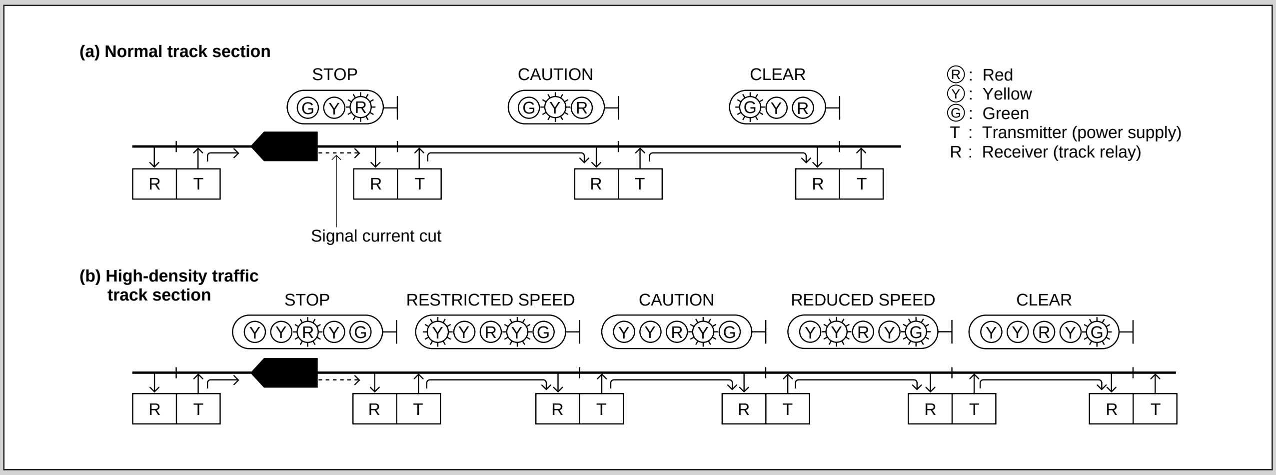
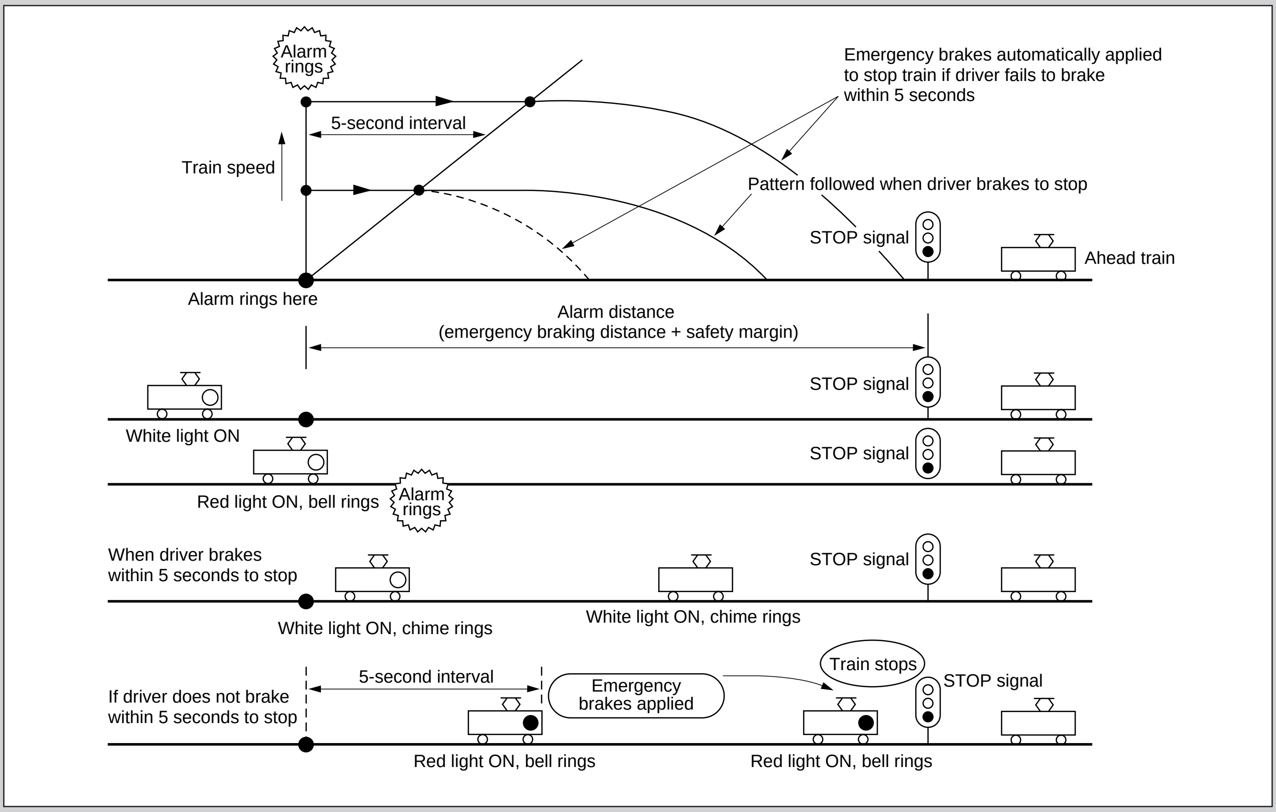


**Figure 3 Operation of ATS-S System**




the two stations that a train is travelling between. The train's departure and arrival are detected by the track circuits at the station entrance and exit.

In the electronic block system, each train has a radio communications device that transmits the train's ID. When the driver is ready to leave a station, he presses a button and the signal changes automatically to green. When the train arrives at the next station, the train's ID is transmitted to a receiver, clearing the block. This type of electronic block system requires fewer staff because the driver basically controls the block.

## Train Control Systems

### Automatic Train Stop (ATS)

The driver must always obey the signal, but the possibility of human error can cause serious accidents. Two rail accidents with serious loss of life in the early 1960s resulted in the installation of the so-called Automatic Train Stop (ATS) system throughout Japan. In the ATS system, an alarm sounds in the cab when the train approaches a stop signal, warning the driver to stop. If he fails to apply the brakes, the ATS stops the train automatically. (Figure 3 shows the operation of the ATS-S system used by the JRs.)

The ATS system uses ground coils installed on the track some distance before signals. If a train passes a coil when the signal aspect is stop, an alarm is sent immediately to the driver, regardless of the train speed. If the driver does not stop within 5 seconds after the alarm is received, the emergency brakes are applied automatically to stop the train. In other words, the emergency brakes are not applied if the driver applies the brakes and presses the Acknowledge button. However, this means that if the driver stops at the ground coil, the train can still proceed under his control through a stop signal. So-called 'absolute stop' ground coils that do not depend on driver ackowledgement are installed in stations and at start signals to prevent any possibility of an accident occurring due to the driver moving ahead by mistake.

A new ATS-P type of system that does not depend on driver acknowledgement has been installed recently, mostly in the Tokyo and Osaka regions. Ground coils communicate between the ground and the trains (Fig. 4) and train braking patterns are monitored by the ground coils to ensure that the trains stop before a stop signal. If a train exceeds the speed permitted by the braking pattern, the service brakes are applied automatically to stop the train. The train can then proceed again, but only in accordance with instructions received from the next coil. This system offers higher safety levels, because it does not depend on driver acknowledgement.

Private railways in Japan have installed an improved version of the ATS-S system throughout most of their networks. This system offers on-board speed verification capability and, since it can apply train brakes automatically, does not depend on driver acknowledgement.

In an intermittent control system using coils, no information is received before the train passes the coil, meaning that signal changes in heavily used sections do not provide a suitable level of compliance. To alleviate this problem, the railways have installed a continuous control ATS system for some track sections. This system uses an audio-frequency (AF) current to transmit ATS-related information along the track circuit, making it possible to receive information on board the train at any time. This system offers similar advantages to the ATC system described below.

## Automatic Train Control (ATC)

The Automatic Train Control (ATC) system was developed for high-speed trains like the shinkansen, which travel so fast that the driver has almost no time to acknowledge trackside signals. The ATC system sends AF signals carrying information about the speed limit for the specific track section along the track circuit (Fig. 5). When these signals are received on board, the train's current speed is compared with the speed limit and the brakes are applied automatically if the train is travelling too fast. The brakes are released as soon as the train slows below the speed limit. This system offers a higher degree of safety, preventing collisions that might be caused by driver error, so it has also been installed in heavily used lines, such as Tokyo's Yamanote Line and some subway lines.

Although the ATC applies the brakes automatically when the train speed exceeds the speed limit, it cannot control the motor power or train stop position when pulling into stations. However, the Automatic Train Operation (ATO) system can automatically control departure from stations, the speed between stations, and the stop position in stations. It has been installed in some subways.

## Digital ATC

The ATC system has been used to control all sections of shinkansen tracks ever since the first shinkansen in 1964 and there has never been a collision. However, ATC has three disadvantages. First, the headway cannot be reduced due to the idle running time between releasing the brakes at one speed limit and applying the brakes at the next slower speed limit. Second, the brakes are applied when the train achieves maximum speed, meaning reduced ride comfort. Third, if the operator wants to run faster trains on the line, all the related relevant wayside and on-board equipment must be changed first.

The digital ATC system uses the track circuits to detect the presence of a train in the section and then transmits digital data from wayside equipment to the train on

**Figure 4 Operation of ATS-P System**

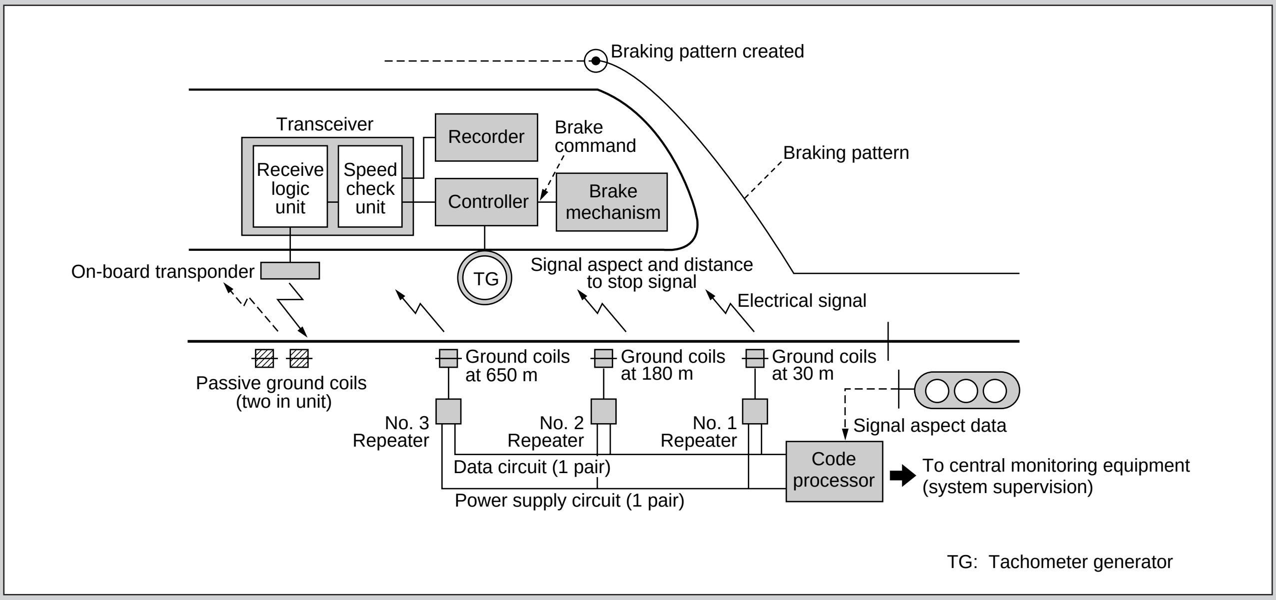


**Figure 5 ATC Train Running Pattern**

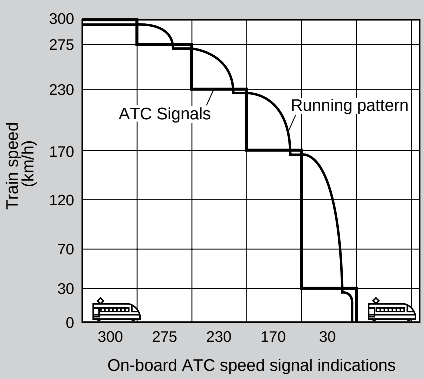
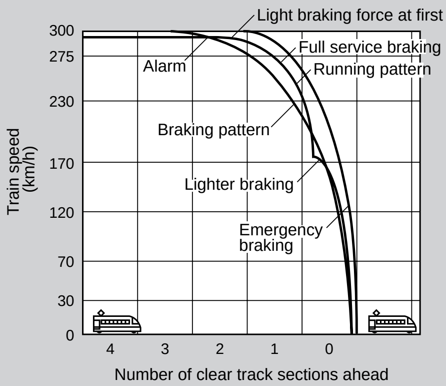



**Figure 6 Digital ATC Train Running Pattern**




the track circuit numbers, the number of clear sections (track circuits) to the next train ahead, and the platform that the train will arrive at. The received data is compared with data about track circuit numbers saved in the train on-board memory and the distance to the next train ahead is computed. The on-board memory also saves data on track gradients, and speed limits over curves and points. All this data forms the basis for ATC decisions when controlling the service brakes and stopping the train.

Figure 6 shows a running pattern generated by the digital ATC system. The created pattern determines the braking curve to stop the train before it enters the next track section ahead occupied by another train. An alarm sounds when the train approaches the braking pattern and the brakes are applied when the braking pattern is exceeded. The brakes are applied lightly first to ensure better ride comfort, and then more strongly until the optimum deceleration is attained. The brakes are applied more lightly when the train speed drops to a set speed below the speed limit. Regulating the braking force in this way permits the train to decelerate in accordance with the braking pattern, while ensuring ride comfort.

There is also an emergency braking pattern outside the normal braking pattern and the ATC system applies the emergency brakes if the train speed exceeds this emergency braking pattern.

The digital ATC system has a number of advantages: (1) Use of one-step brake control permits high-density operations because there is no idle running time due to operation delay between brake release at the intermediate speed limit stage. (2) Trains can run at the optimum speed with no need to start early deceleration because braking patterns can be created for any type of rolling stock based on data from wayside equipment indicating the distance to the next train ahead. This makes mixed operation of express, local, and freight trains on the same track possible at the optimum speed. (3) There is no need to change the wayside ATC equipment when running faster trains in the future. The Railway Technical Research Institute (RTRI) is currently conducting basic research into an improved and innovative ATC for Tokyo's Yamanote Line and the shinkansen lines.

## CARAT and ATACS

Use of track circuits to detect trains in blocks and to send transmissions from the ground to the train requires a lot of wayside equipment. A Computer And Radio Aided Train control system (CARAT) is being developed to reduce the equipment amount and permit on-board detection of train locations without using track circuits. CARAT will control train traffic by transmitting information between the ground and trains. The system is similar to the digital ATC system in the sense that wayside equipment will transmit information on the distance to the next train ahead, and braking patterns will be created on board. However, CARAT will be able to obtain accurate information on train locations, and transmission of information from the trains to the wayside equipment will make it possible to create moving blocks. As Figure 7 shows, CARAT will be a comprehensive train control system capable of transmitting commands from trains to station points and level crossings. RTRI has already conducted CARAT verification experiments on JR's Joetsu Shinkansen. JR East has conducted subsequent performance tests on its Senseki Line, to test the Advanced Train Administration and Communications System (ATACS), which uses radio telecommunications. One purpose of these tests was to verify that the system is safe for track maintenance personnel. Development of these systems is continuing, with every reason to believe that they will soon come into service.

**Figure 7 CARAT System**

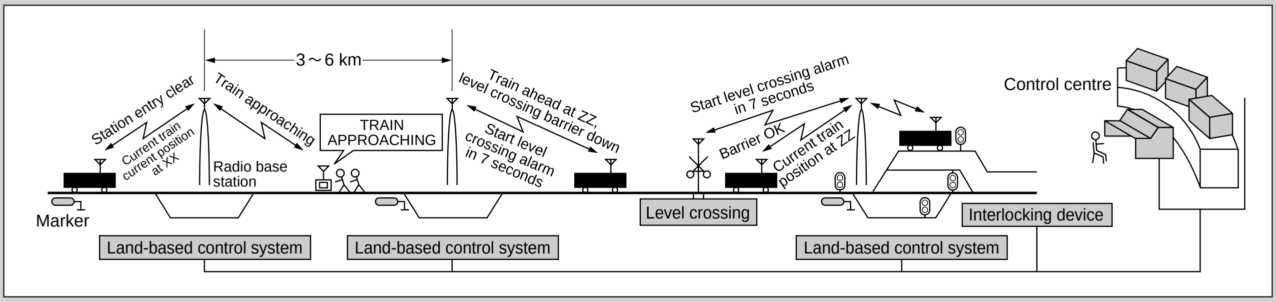
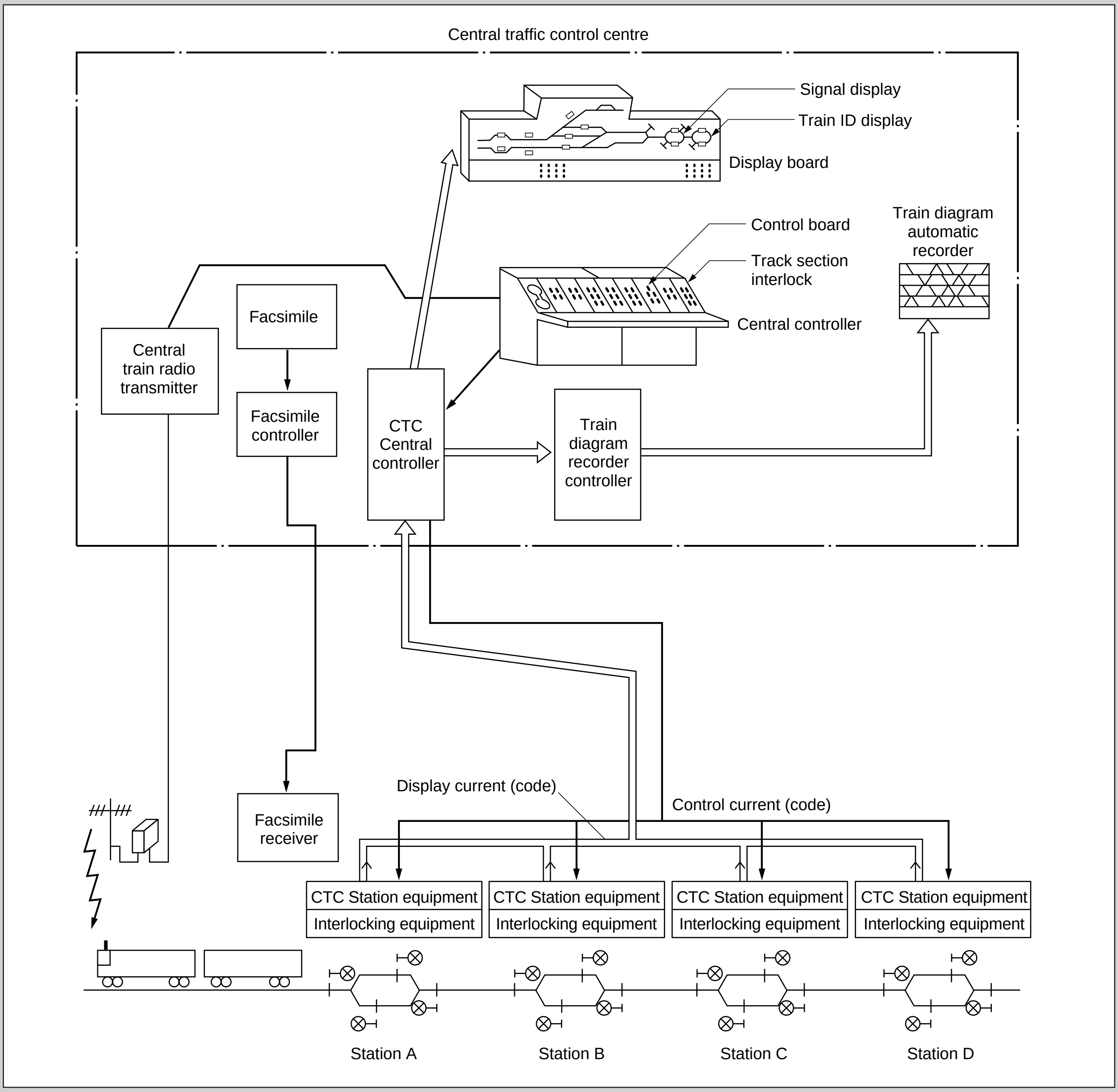



**Figure 8 CTC System**



## Train Traffic Control Systems

### CTC and PRC Train traffic control systems

Train traffic control requires full and continuous knowledge of the train operations. In a conventional traffic control system, stations use telephone communications to establish a route, but this process is too slow and inefficient for modern rail traffic volumes.

Centralized Traffic Control (CTC) provides the traffic control centre with information on the situation of all trains in all track sections and permits the centre to control train routes directly (Fig. 8). The heart of the centre is a number of centralized display and control panels, connected to stations and trains by various types of equipment: radio equipment, command telephones, train schedule recorders, train number display units, etc.

When the CTC system was first introduced, train routing was controlled directly by Centre personnel. However, the increasing number of trains overwhelmed the system, prompting development of the computerized Programmed Route Control (PRC) system.

CTC was used for the first shinkansen operations in 1964, but routing decisions were automated in 1972. The shinkansen COMputer aided TRAffic Control system (COMTRAC) has a number of advanced functions, including route control, traffic coordination, rolling stock management, and passenger information services. COMTRAC is an extremely efficient traffic control system, so it is used for some non-shinkansen services as well. The JRs and private railways have installed or are installing it on most track sections with high-density or high-priority operations.

### COSMOS and ATOS

JR East improved the COMTRAC system in 1998 when it opened the Hokuriku Shinkansen. This system is called COSMOS (COmputerized Safety Maintenance and Operation Systems for Shinkansen) and integrates existing COMTRAC functions with traffic planning, traffic administration, maintenance equipment control, and rolling stock control. Route control is not under centralized control. Instead, routing responsibility is shared with individual stations so that if the system fails at one or several stations or at the Control Centre, the effect on the system as a whole will be minimized and some traffic will continue to flow.

The Autonomous decentralized Transport Operation System (ATOS), a new and very powerful traffic control system is being implemented for the Tokyo region to control 17 track sections, 390 stations (140 interlocked), and 6200 daily train operations. The system first entered service in 1996 on JR East's Chuo Line.

ATOS and COSMOS are very similar—ATOS began first, but efforts were focused on COSMOS as the shinkansen control system. ATOS is far bigger than COSMOS, so the latter was put into service sooner.

## Wireless Communications Devices

### Narrow-gauge train radio communications

Train safety would be far lower without radio communications between train crews and control centre staff. Before the introduction of train radio, a crew member would have to use a trackside railway telephone to call the control centre if an accident occurred outside a station. Today, the train crew can communicate immediately with the control centre using the train radio.

Railways use duplex, semi-duplex and simplex radio telecommunications for non-shinkansen lines. Duplex is used on sections with heavy traffic, semi-duplex is used on high-priority sections with less dense traffic, and simplex is used on other track sections. The simplex system is actually an extension of the existing system that drivers and train crew already used to communicate with each other. Semi-duplex and simplex systems are also used for communication between train crews.

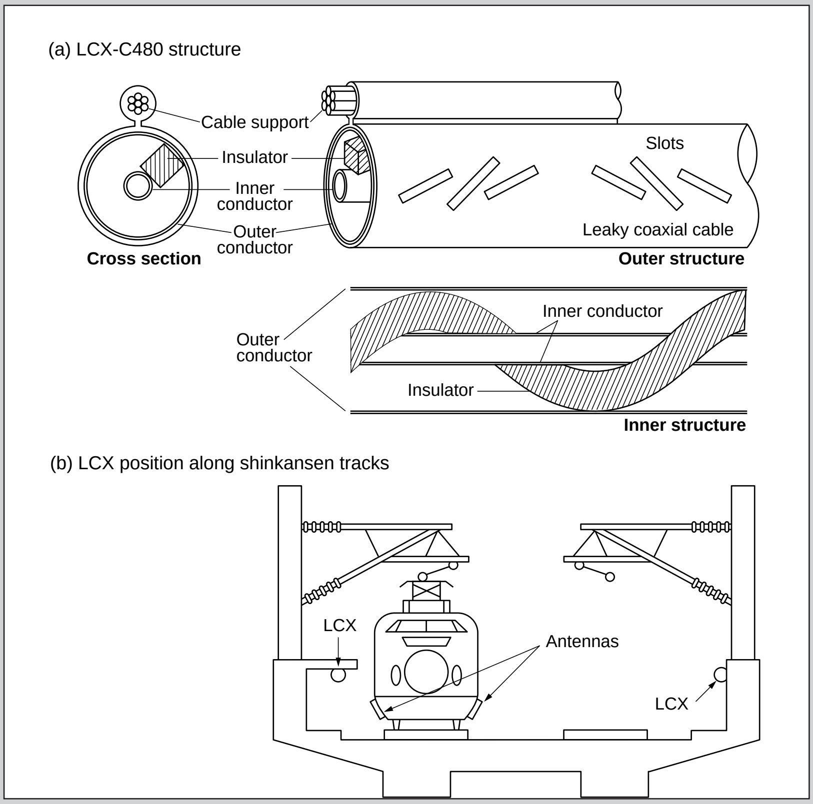
Japan's private railways also use train radio communications. The type depends

*COSMOS Shinkansen command centre* *(JR East)* on the specific track sections. Private trains also have limited-range (1 km) radio equipment that broadcasts an accident warning signal directly to approaching trains in order to prevent a second accident.

### Shinkansen radio communications

Shinkansen trains have used radio communications since the very first services in 1964 but Japan's mountainous topography makes radio communications very difficult in some locations. Another problem of the early shinkansen days was the small number of available radio channels. To ensure better reliability and to increase the number of communications channels, leaky coaxial (LCX) cables were laid first along the full length of both the Tohoku Shinkansen and Joetsu Shinkansen to transmit data and messages to and from command and track telephones, and on-board public telephones. LCX cables were subsequently laid along the Tokaido Shinkansen as well. Figure 9 shows the installation details; the supported LCX cable is run along the noise-control barrier beside the track, with suitable-size slots cut into the cable to allow the signal to leak out.

**Figure 9 Installation of Leaky Coaxial Cable along Shinkansen Tracks**




## Conclusion

This article has described some signalling equipment used by Japanese railways to ensure safe railway operations. Other devices, such as interlocked signals and points in stations are used as well. Most of the many thousands of interlocks are either relay or solid-state electronic interlocks and there are about 1000 of the latter now in service.

In addition, almost all level crossings in Japan are controlled by automatic devices that detect an approaching train and lower the barriers automatically. Some level crossings on very busy roads have extra obstruction warning devices to detect motor vehicles on the crossing when the barriers come down and stop the approaching train.

However, although all signalling devices play an essential role in railway safety, there is still no substitute for skilled, conscientious and vigilant operations staff. ■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