Operation Control and Signaling System for High-Speed Lines

Klaus H. Hümmer

Increasing traffic demand combined with the consequent congestions of road and air traffic has led several European countries to improve passenger rail service by introducing fast, intercity links and new high-speed lines. The signaling for the German Intercity-Express high-speed trains consists of continuous automatic train control (CATC), decentralized microcomputer interlockings, and operation control centers for automatic train supervision. The CATC is an automatic cab-signaling system transmitting, via an induction cable installed along the track, an array of data from track to train and vice versa. The most important signals are maximum speed, target speed, and distance-to-go. On-board fail-safe computers calculate the required speed, control the train, and supervise the performance. Microcomputer interlockings work on a fail-safe, 2-out-of-2 technique with full redundancy. Control range for each central interlocking can reach 40 to 60 mi. The software consists of a basic operating system and special railway applications. Track monitoring is achieved by jointless audio track circuits with a frequency range of 4 to 6 kHz and 9 to 17 kHz, and a frequency shift keying (FSK) code bit-pattern to make the circuits immune to interference. Train movements are operated from control centers spaced at approximately 200-mi intervals along the lines. Train routing is implemented by means of train numbers. The progress of trains is monitored on indication panels, track lay-out monitors, and train graphs that allow dispatchers to react quickly. Links between control centers and the line is via a fiber-optic PCM high-speed communication system. Automatic train supervision, decentralized microcomputer interlockings, and continuous automatic train control are interconnected by well-defined data interfaces.

In Europe, but not only there, railways have been enjoying a renaissance during the past 10 years. There are clearly two reasons for this: the increasingly chaotic conditions on highways and the congested airspace with its accompanying flight delays.

For some years now, in the major European countries, high-speed rail lines have been built and, step-by-step, put into service. A European network for high-speed lines is planned for the future. Same branches of it have already been realized (Figure 1). In France, two lines are operating at present. In Spain, the high-speed Madrid–Sevilla line is under construction.

As long ago as the early 1970s, the German Federal Railway started an Intercity-Express service linking 50 major towns in Germany. Speeds of 120 mph were achieved on existing lines. Running parallel to faster service on existing lines in Germany are newly constructed lines and the modern, high-speed train known as "ICE," the acronym of Intercity-Express. In June 1991, the German Federal Railway put high-speed traffic into service along the first 270 mi of the newly constructed Hannover–Würzburg and Mannheim–Stuttgart lines. The current line used by high-speed trains from Hamburg in the north of Germany to Munich in the south is 570 mi long. The ICE network will be extended next year.

Siemens AG, Transportation Systems Group, Ackerstrasse 22, W-3300 Braunschweig, Germany.

Today, the new ICE trains travel to schedule at a speed of 160 mph. The vehicles are authorized to travel at 175 mph, which they do when there are train delays. The signaling system is designed for 200 mph.

Because of the hilly countryside, many bridges and tunnels had to be built. To make that large investment yield a better profit, freight trains also travel on high-speed lines. With this in mind, line gradients have been limited to 1.25 percent.

The chosen signaling system permits optimal traffic flow even when there is mixed traffic of high-speed trains and freight trains. The high-speed ICE is the latest technology with a three-phase motor, power recovery in network when braking, data transmission within the trains using fiber-optic cable, and on-board diagnostic systems. The cabs and passenger cars are pressure-proof because of the strong changes of air pressure at the entrances and exits of tunnels.

An ICE train set is made up of a traction unit at each end and 14 passenger cars. First and second class provide a seating capacity of 759. In 1988, a prototype of this train reached a speed of 253 mph, a world record. But however fast the trains themselves may be, the efficiency of high-speed lines is largely determined by the capability of the signaling and operation control system employed.

THE COMPLETE SYSTEM

Railway signaling equipment must guarantee the protection of train movements and permit an efficient use of the line by keeping headways short. The equipment for signaling and operation control on the new German high-speed lines is characterized by the application of electronic technology and by design and testing done in accordance with the high-safety level of German Railways specifications.

The complete system is made up of continuous automatic train control (CATC) for protecting trains and for cab signaling, on-board automatic speed control (ASC), decentralized microcomputer interlockings for safeguarding routes, and the operation control center's automatic train supervision (ATS) (Figure 2).

The CATC System

The basic requirements for the signaling system result from the fact that the maximum speed is 175 mph. At this high

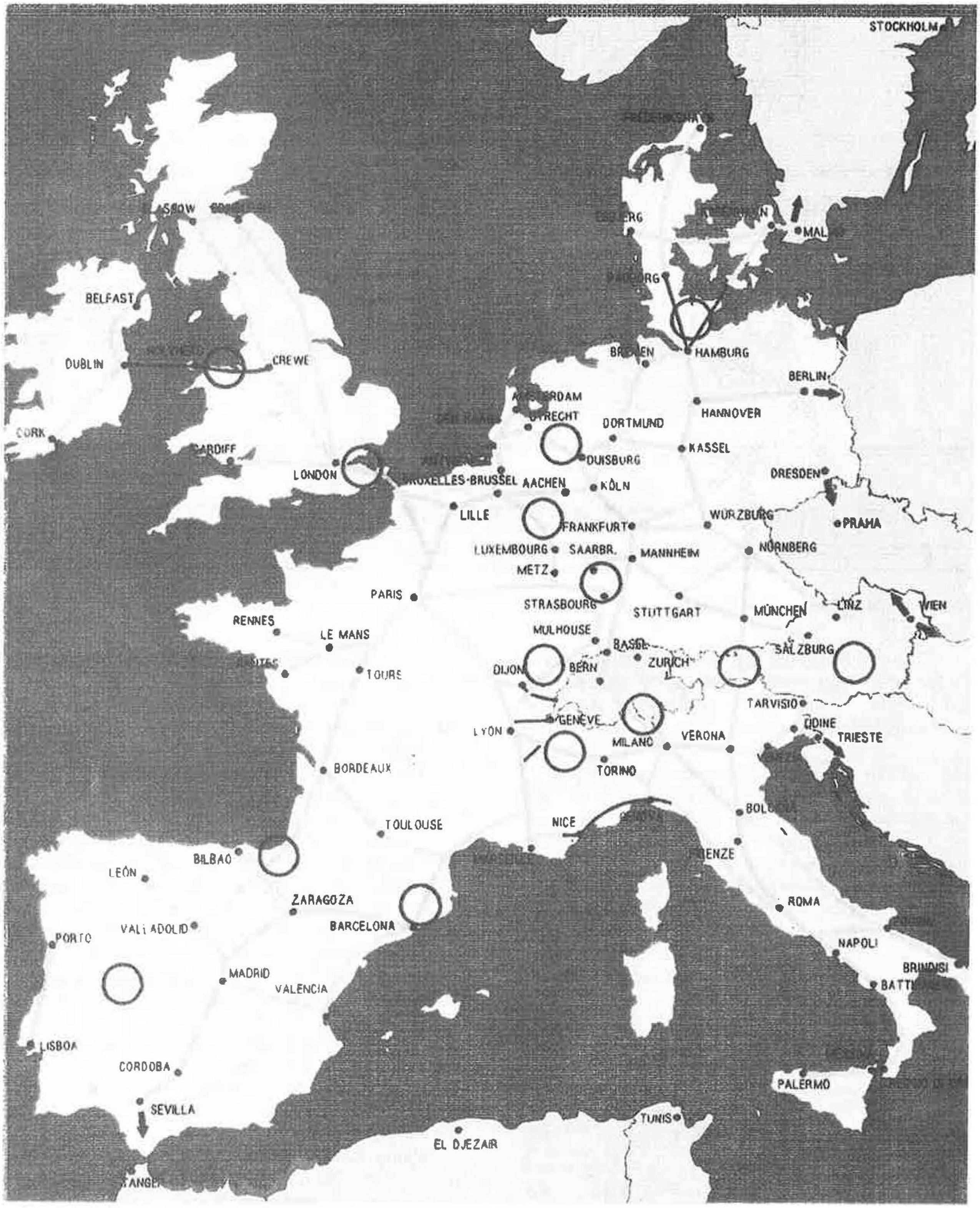

FIGURE 1 Planned European high-speed network.

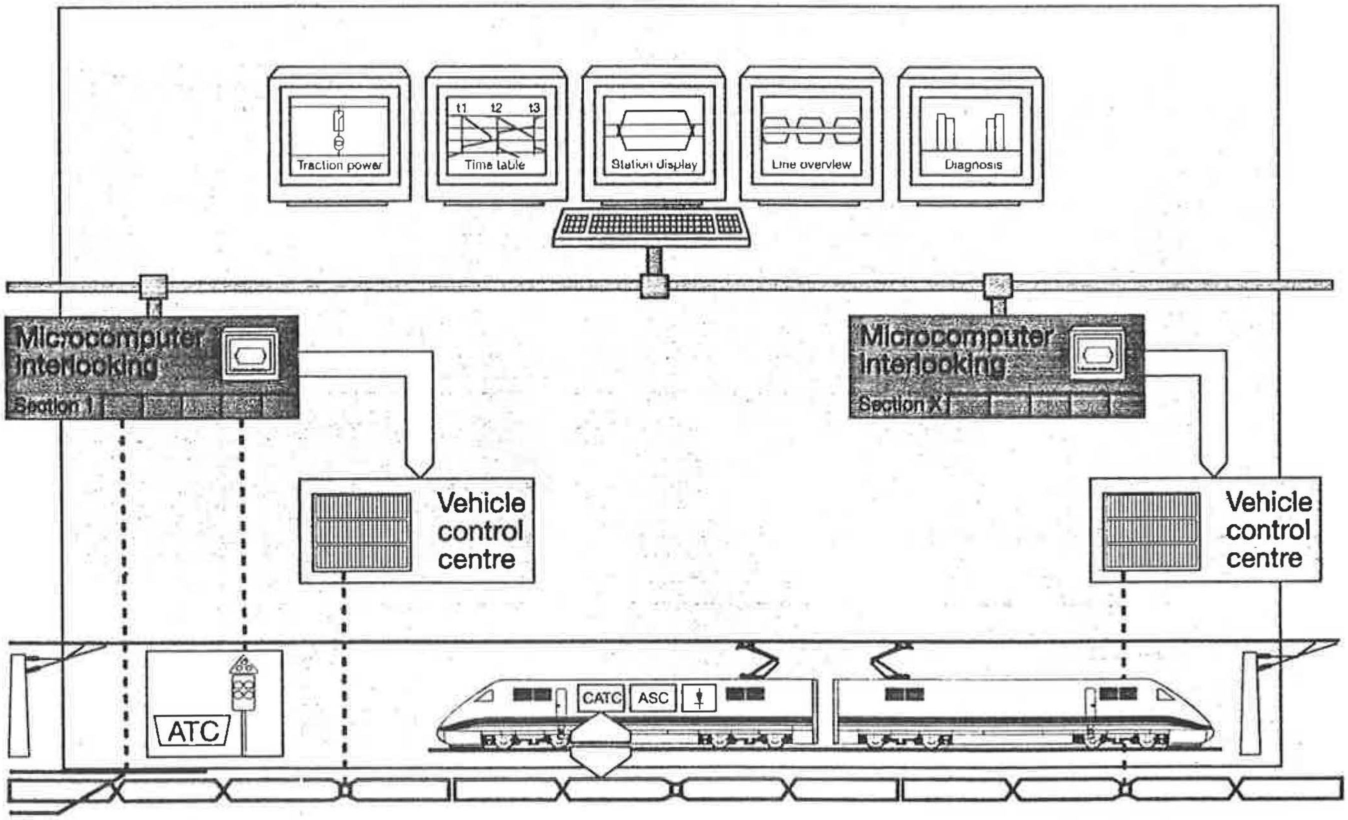

FIGURE 2 Train control for high-speed lines.

speed, the engine driver is not able to observe optical signal aspects. The braking distance of a train traveling at this speed at a braking rate of 0.5 m/s is 3.7 mi. For this reason, it is necessary to install a continuous automatic train control system.

On the German high-speed lines, trains are controlled by the CATC system known as the LZB 72-80, which permits either automatic or driver operation. Among the principal features of the CATC (Figure 3) are the unmanned vehicle control centers along the line at great distances. Each vehicle control center has a 2-out-of-3 computer system for handling all data processing. This configuration guarantees fail-safe and reliable operation. Two computers are needed for the vital operation by cross-comparing the outputs, the third computer serves as a hot standby. The vehicle control center also includes the corresponding equipment for transmitting data to the vehicles, to the other vehicle control centers, and for receiving data from the interlockings.

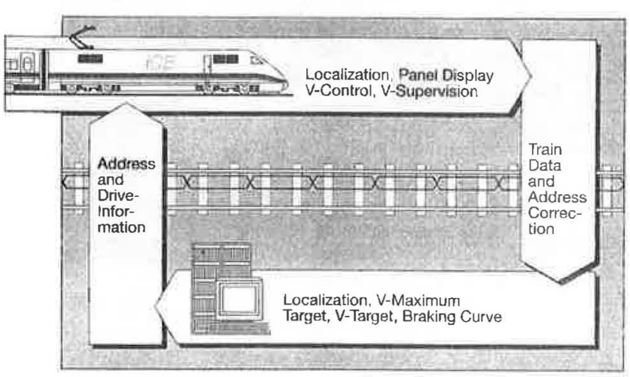

FIGURE 3 CATC basic functions.

Another feature of the CATC is storage of permanent controlled-area data in the computer system of the vehicle control center, along with data on line gradients, currently permitted line speeds, and, if applicable, signal locations. Variable data such as the location of the trains, individual braking efficiency of trains, and positions are transmitted to the vehicle control centers by the trains and interlockings.

The vehicle control center computer calculates the running orders to be transmitted to the on-board computers: target speed, available distance to the next target, and the number of the braking curve to be used in the train-borne computer. The trains calculate their driving and braking profile and drive in accordance with this limitation at maximum permissible speed.

Changes in line data, such as permitted maximum speed along track construction sections, can be input into a vehicle control center. The data transmission functions exactly as a closed-loop data transmission between train and track, and track and train (Figure 4).

A double-track section of up to 60 mi in length can be monitored and controlled from one CATC control center. In practice, however, on the new high-speed lines, section of 25 to 40 mi is supervised and controlled by a single vehicle control center.

Trains are traveling nearly at moving block intervals—the shortest possible headway. At a speed of 200 mph, trains can travel at 2-min intervals. The vehicle control center provides

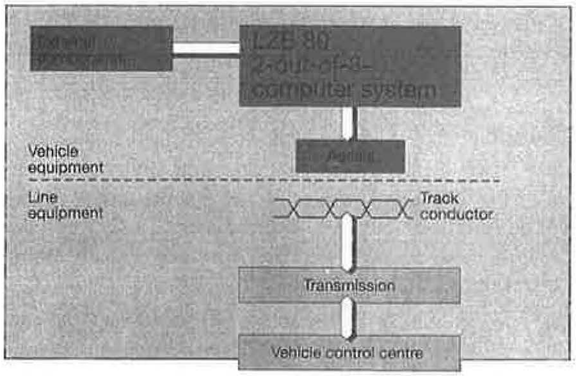

FIGURE 4 LZB 80 continuous automatic train control.

all trains within its control range with information for observing the distance between trains and with the permitted speed. The traction unit is addressed by its location when the vehicle control center is sending data. The on-board computer derives the relative location of the train from the odometer and crossings of a wire-loop in the track and calculates the current permitted speed on the basis of the distance to the next target and the target speed transmitted from the vehicle control center. The vehicle is automatically braked if the permitted speed is exceeded (Figure 5).

The vehicle computer also calculates the data for automatic speed control as well as the permitted speed from the intermittent automatic train control (ATC) system, when this is employed as a backup system.

Data exchange between vehicle control center and train is bidirectional. Transmission is via a pair of wires laid between the rails. The wires are crossed at intervals of 110 yards. The transpositions give the exact location of train. The receiving antennas are connected with the two channels of the receiver, which amplifies and demodulates the call-telegrams sent from the vehicle control center. The receiver forms the information "transposition point" from the phase change of the receiving signals at transposition points. The location and the driving information is evaluated by the train-borne 2-out-of-3 computer and processed for controlling speed and activating the brakes. The train answers the call of the vehicle control center via its sending antennas, transmitting its location, locomotive number, train length, and its actual speed (Figure 6).

Several trains can be in the area of one loop at the same time with a theoretical length of 8 mi. They are individually addressed by the LZB control center and provided with information in respect of their run. For availability reasons, the loop is split into sections of 300 m, which are individually fed by transmitters and receivers with identical information. The data transmission frequency from vehicle control center to train is 36 kilocycles/sec, the data-signaling rate is 1.2 k/bit per second (bps). In the other direction, from train to track, the frequency 56 kHz is used with a data rate of 600 bps. The carrier frequencies are frequency modulated. The transmitted data are coded for hamming distance 4.

Future modifications are planned that will allow the LZB data transmission to be via radio instead of via cable loop. A point to be emphasized here is that the LZB 72-80 system provides bidirectional transmission of data. This ensures maximum safety and efficiency of control. The system takes into consideration the individual train characteristics and topography of the line, and so achieves close train headways and maximum line-carrying capacity. The method of transmission of target information (instead of speed information) is a major advantage over coded track circuit systems in mixed traffic applications.

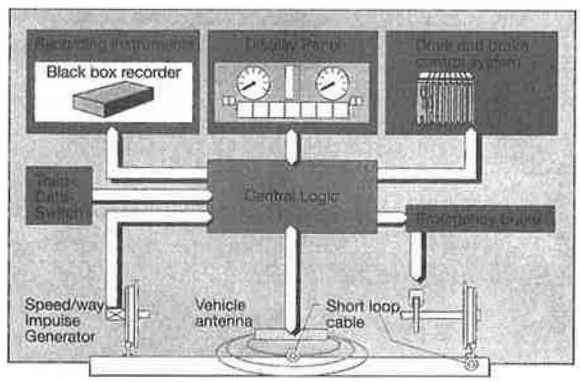

FIGURE 6 CATC train-carried equipment.

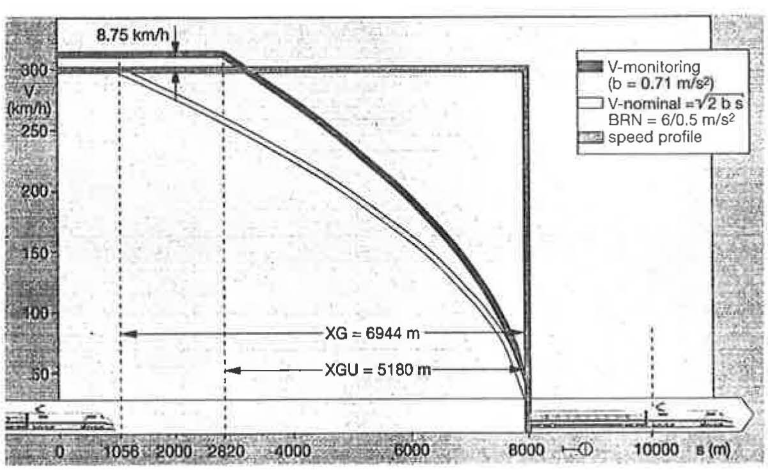

FIGURE 5 CATC determination of speed.

Figure 7 shows the cab of the ICE high-speed train with the display of the CATC system LZB 72-80. The German Federal Railway has more than 750 mi of line equipped with this system. The CATC system has been in operation for 15 yrs on high-speed lines catering to speeds of up to 120 mph. The second generation of the LZB 72-80 is working now very successfully and reliably for trains with speeds of 175 mph. About 400 locomotives and ICE high-speed trains are equipped with this system. It is in accordance with the ORE-A46 recommendation of the International Union of Railroads (UIC). Therefore, it will be introduced also on other new lines in Europe, such as the future high-speed line in Spain.

Interlockings

Route setting and locking, points, track vacancy detection and equipment (and, if applicable, line signals) are to be linked by interlocking. Germany's new high-speed lines are equipped mainly with electronic interlocking. These interlockings provide safeguarded routes and also give information to vehicle control centers. The microcomputer (MC) interlockings, with solid-state technology, have a very high level of safety. Each type of electronic interlocking is type-tested for safety by the German Federal Railway. These MC interlockings work to the principle of geographical circuitry logic. Therefore, the entire safety logic is programmed and tested just once for one railway authority. The general layout of MC interlocking is shown in Figure 8.

FIGURE 7 ICE-cab with CATC system LZB 80.

The interlocking software is divided into basic operating system, special railway applications, and station-specific software. The individual interlockings are project-planned and only the function is tested, as the system's safety has already been approved. This combination provides the safest and most economic procedure.

Interlocking fail-safe function is provided by cross-checking results of the two-channel microcomputer system, SIMIS (shown on the right side of Figure 9). The results of the two parallel computer channels are continuously cross-checked. Only if the results are equal will the command be executed. Availability is made by employing full redundancy, using two computer systems each with a SIMIS dual-channel computer system. In the dual computers the same software is used. Figure 11 shows the hardware for fail-safe microcomputer interlocking.

Via a data transmission line, each main interlocking is linked to several extended interlocking components with decentralized section computers. The maximum distance between a main interlocking and the extended interlocking components is 7.5 mi. Up to nine decentralized interlockings can be connected to one main interlocking, which has display and operating facilities. Therefore, at maximum, up to 60 mi of line can be controlled and safeguarded by one main MC interlocking. Figure 10 shows, as an example, the installed MC interlocking Orxhausen, controlling a long section of the ICE high-speed line from Hannover to Würzburg.

Track Monitoring

Special track vacancy detection equipment has been developed for use with the most modern high-speed trains. This equipment is immune from electromagnetic interference and is fail-safe. It functions with a frequency shift keyed (FSK) coded 8-bit pattern at an audio frequency range of 4 kilocycles/s to 6 kilocycles for block sections and 9 to 17 kilocycles/s in stations.

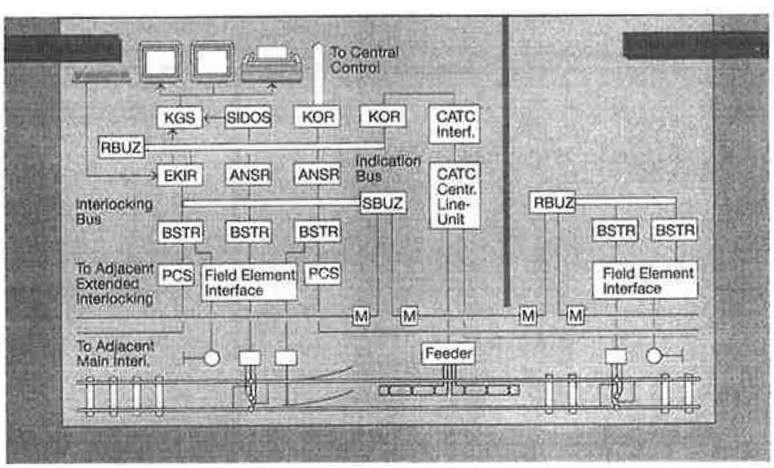

FIGURE 8 Microcomputer interlocking general layout.

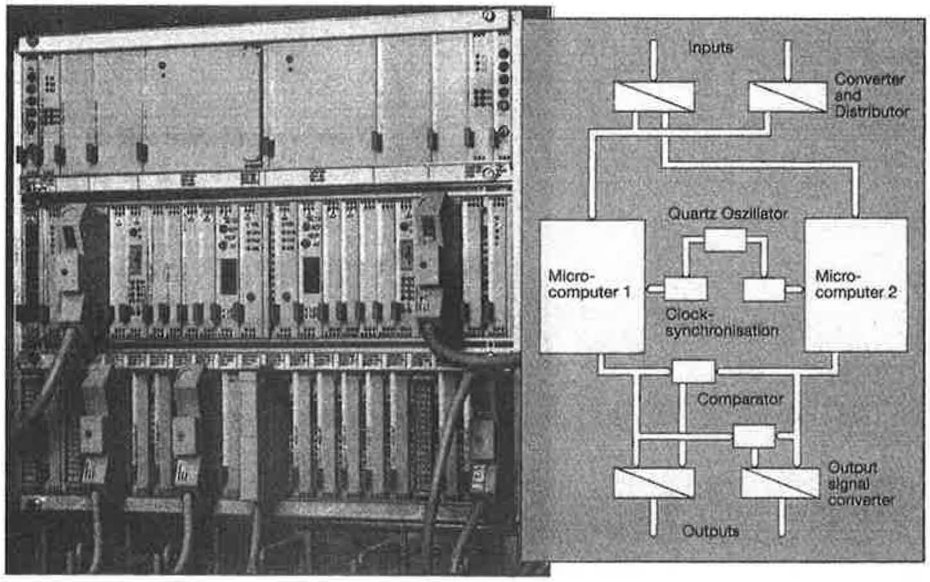

FIGURE 9 Fail-safe microcomputer interlocking.

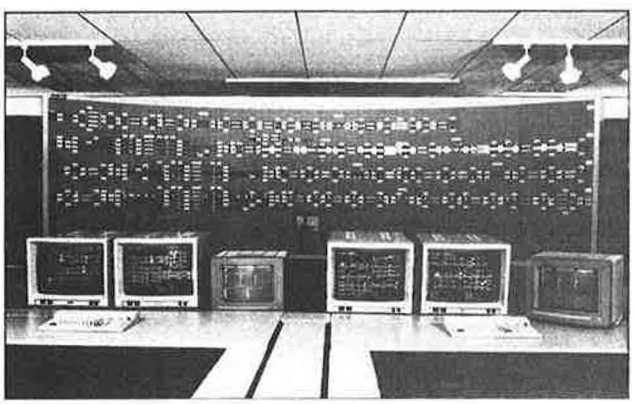

FIGURE 10 Microcomputer interlocking Orxhausen.

The track circuits naturally have electric joints, so that the rails are not required to be cut. This enables an optimal traction current return to the power station. The length of a center-fed circuit for blocks is up to 1.2 mi. This type of track circuit uses the most modern electronic components. They are remote-controlled; that is, transmitter and receiver are accommodated in signal cabins. As a result, reliability and availability are excellent.

Line Operation

Line operation functions as follows: Computer-aided traffic control centers monitor line sections of approximately 200 mi on high-speed lines. They supervise traffic movements for adherence to timetable and to manage traffic control in exceptional cases.

Route protection and control is automatically performed. The CATC system provides for the protection and control of trains. A train can be controlled by the driver, who refers to a cab display, or be controlled automatically in accordance with the current calculated maximum permitted speed.

For train operation automatic train supervision is installed. The high-speed trains set their routes by themselves. Each train has its own identification number. As the train travels along the high-speed line, its number is switched from interlocking to interlocking. This identification permits individual train tracking throughout the controlled area. The safeguarded route is automatically established as the train proceeds over the line. There is no operational control by a dispatcher. Location and description of the train are transmitted from each process area to the operation control center. Here, the computer updates the train graphs that are shown on color monitor

The stored timetable data are compared with the current train run data. Train delays can be immediately perceived and decisions made by the dispatcher. Traffic supervisors are also aided by complete line displays, with points and track sections. Full line displays can be either shown on monitors or on a panorama panel. The operation control and signaling system is part of the entire transportation control system for high-speed lines.

The different operating areas, such as train control, train monitoring, power supply, passenger information, station supervision, and so on, are connected by local area network to a multifunctional, integrated telecontrol system (Figure 11). Standard operating systems such as UNIX and standard hardware are used for the work stations.

The complete system handles all controlling and supervising functions (Figure 12). First, there is the already described train operation area for supervising train movements, including train operation and line overview. Other features of the transportation control system are passenger information, the public address system, track-to-train radio, and closed circuit television for monitoring platforms as well as power management for electric traction and building control. Building control includes fire protection and the supervision of elevators.

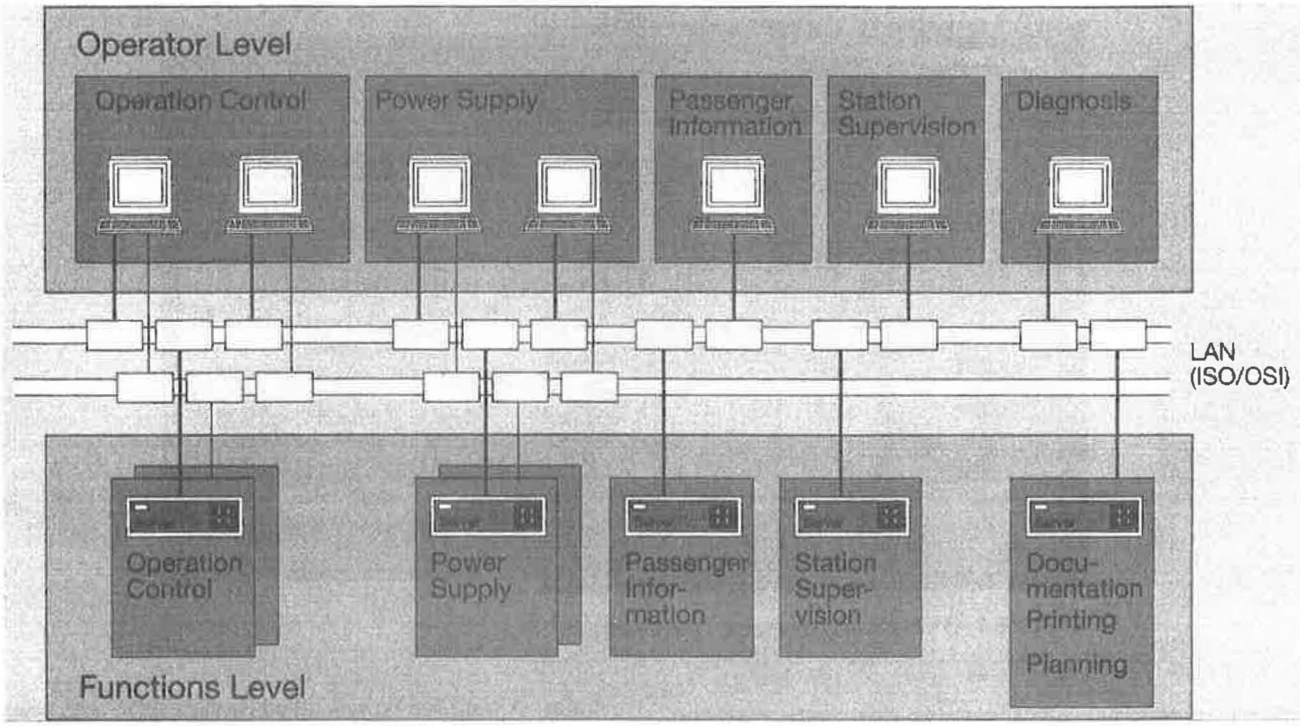

FIGURE 11 Multifunction integrated operations control center.

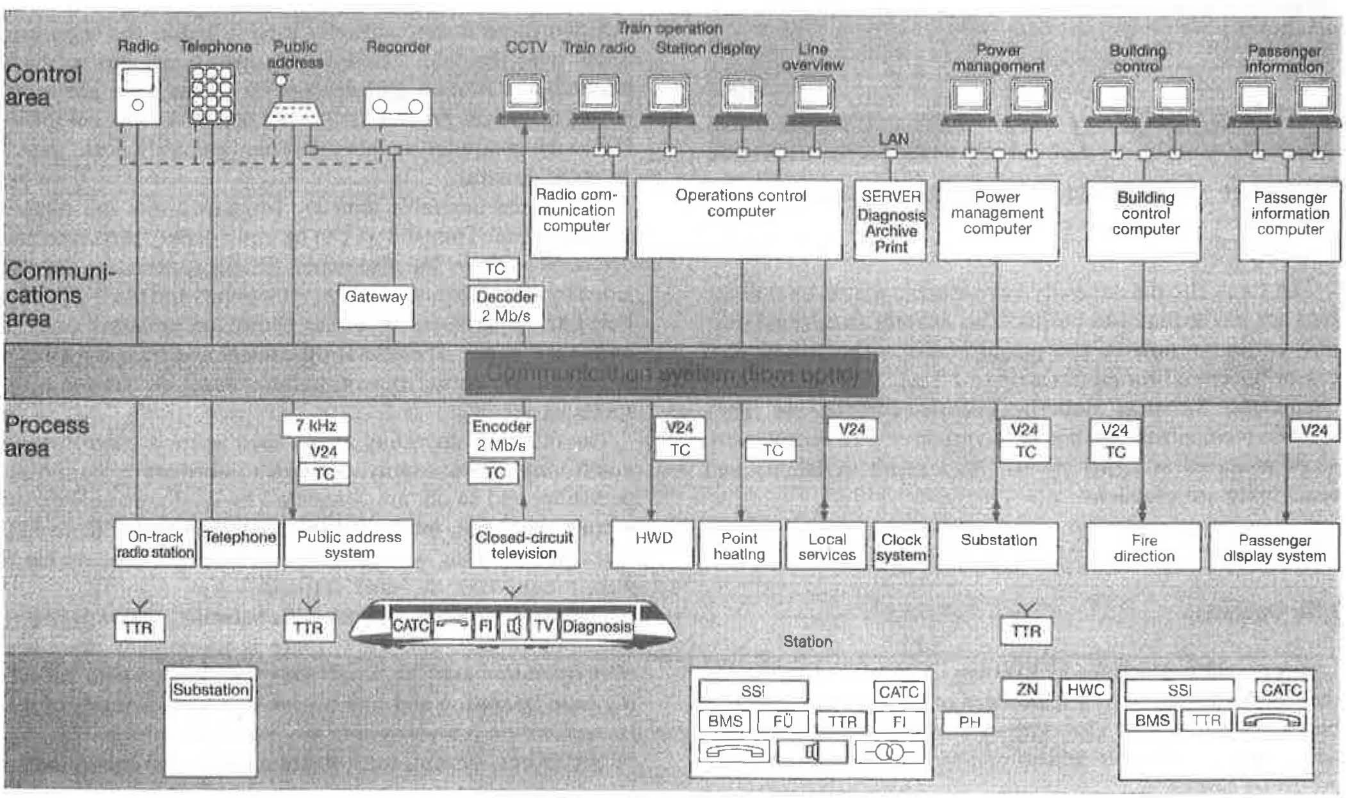

FIGURE 12 Transportation control system for high-speed lines.

Information to and from the control center is transmitted by metropolitan area network via a fiber-optic pulse-code modulated high-speed communication system.

SUMMARY

The operation control and signaling systems for the ICE high-speed lines are clearly structured. Automatic train supervision, decentralized microcomputer interlockings, and continuous automatic train control are interconnected by well-defined data interfaces. All equipment is well proved.

The system is characterized by a very high level of safety and availability. It is flexible and can be adapted very easily to new requirements. Modern electronic hardware and a straightforward structure of software guarantee successful application both now and in the future.

ACKNOWLEDGMENT

The author would like to thank the director of the technology, quality assurance, and standards department of Siemens Transportation Systems Group for permission to publish this paper.