Automatic Train Control

Anders Sjöberg

The Nordic Railway Administrations have decided to increase the safety of the railway lines by introducing automatic train control systems on lines carrying a large amount of traffic. The systems, which are based on LM Ericsson's system JZG 700, will provide assistance for the driver and, if necessary, brake the train. In this article the reasons, possible methods and safety requirements for automatic train control are discussed, and the functions and facilities of system JZG 700 are described. The emphasis is placed on the method for track-to-train transmission and the ways and means of using computers in safety systems. Finally a summary is given of the current installation programs.

UDC 656.25

The low friction between wheel and rail means that the railway is a transport medium with low energy consumption, but it also means that the braking distances of trains are very long. A freight train at 100 km/h can have a braking distance of 1200 m. An express train at 130 km/h needs about 700 m to stop. In many cases the train driver's range of vision is less than that.

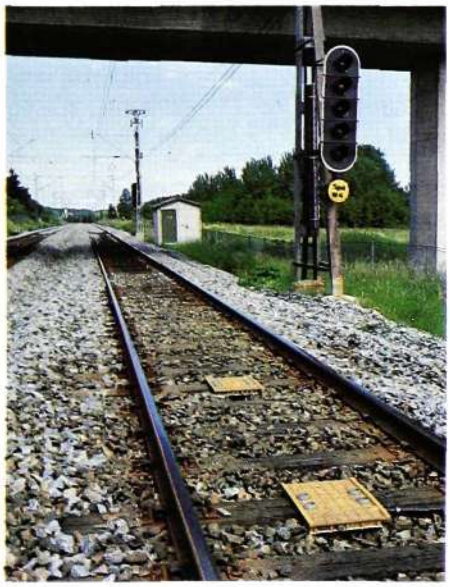


Fig. 1
The beacons are installed in pairs in order to increase the reliability of the system. The beacons are encoded so that the evaluation equipment can determine for which direction of travel the information applies

The driver is therefore informed about the situation ahead by means of light signals and signs. Knowing the characteristics of the train, such as the braking distance, he can then adjust the speed to provide safe and steady driving.

Safety systems ensure that the signals cannot give dangerous information even if a fault occurs. Thus, if the driver acts upon the signal information, no collisions can occur nor any derailment because of excessive speed.

Train drivers, like all other human beings, can make mistakes. How often depends on, for example, how complicated his job is. Increasing traffic volume, with more information to the driver, additional tasks and higher speeds, make the driver's job more difficult.

The railway administrations are introducing systems for automatic train control (ATC) in order to reduce the risk of accidents caused by the train driver. ATC systems must

- transmit information from the track to the train
- present the information in such a way that the driver's work is simplified
- supervise that the train is driven safely, warn the driver in the case of danger and, if necessary, brake the train.

Different types of ATC

ATC systems can work with continuous or intermittent transfer of information, and the amount of information can be small or large.

Continuous systems, where information is continuously transmitted from the track to the train, are comparatively expensive, but are suitable for underground railways and other tracks with a high traffic load. LM Ericsson have supplied continuous systems since 1950.

The predecessor of the ATC systems with intermittent transmission of information was mechanical train stops. LM Ericsson have delivered such systems to several countries. The transmission to the train is carried out by a lever which hits a brake valve on the passing train that is to be braked.

Nowadays the intermittent track-to-train transmission is usually inductive. The track is equipped with beacons, fig. 1. The previous beacon systems have only been able to send a few messages to the train, but both the demands and the available facilities are now greater.

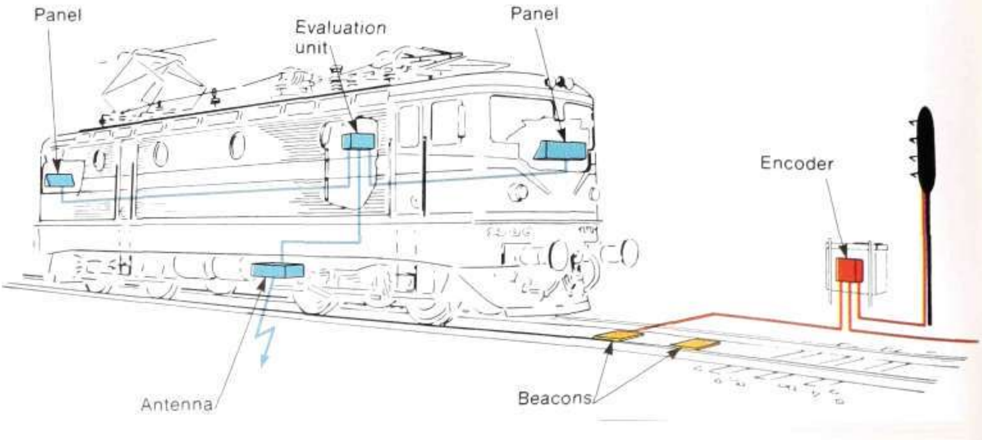


Fig. 2
The units in an ATC system that are installed in the track and the locomotive

ANDERS SJÖBERG
Signalling Systems Department
Telefonaktiebolaget LM Ericsson

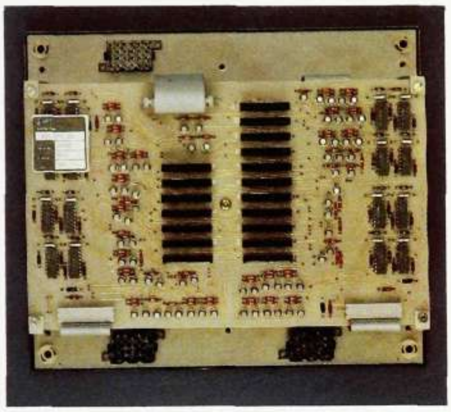
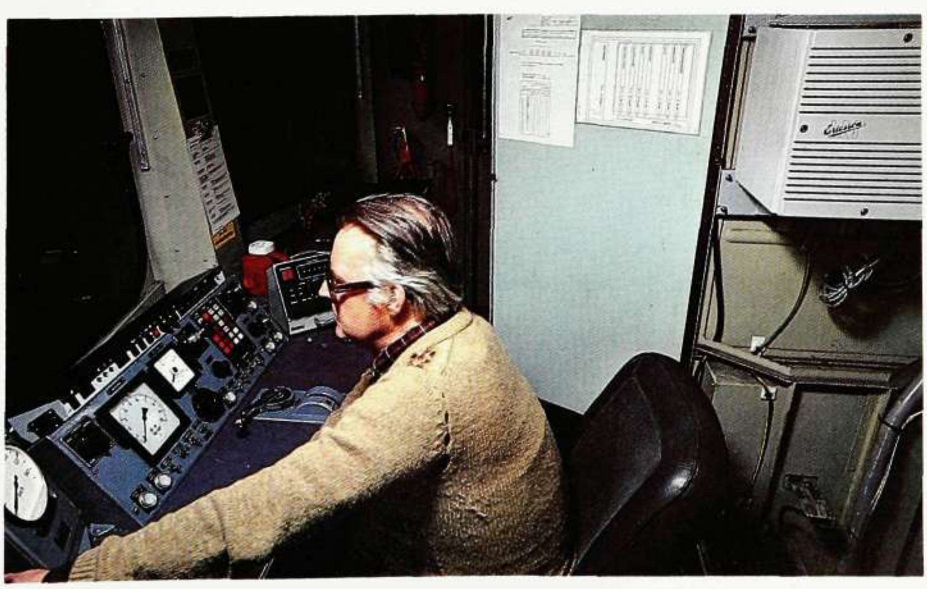


Fig. 3
Encoder

Fig. 4
A driver's cabin with control panel and evaluation unit (top, right)



Demand regarding quantity of information

A modern ATC system must

- *warn or brake* in all situations that can be dangerous
- *not warn or brake unnecessarily*, since this would reduce the traffic capacity and reduce the driver's confidence in the system.

The ATC system must therefore handle approximately the same amount of information as the driver whose driving the system is to supervise.

JZG 700 has the required high information capacity. Furthermore it is possible to start by installing a simple system, which has certain limitations as regards traffic capacity. Later on, when the demand grows and experience has been gained, the ambition level can be increased and additional equipment installed, for example at a certain signal, along a line, for a certain type of locomotive or more generally throughout the system.

Safety requirements

For reasons of safety the ATC system must never let trains be driven at a speed that exceeds the permissible limit. The system must be safe even if a fault occurs. This applies for all types of faults, including design and programming faults.

Fail safe does not mean freedom from faults. For example, if a fault occurs, the ATC system may interpret a "proceed" message as "stop" and brake the train. A stop message, on the other hand, must never be interpreted as "proceed". Availability, i.e. the amount of time when the equipment works accurately, and fail safe are to a certain extent in opposition. Redundancy in code words or duplication of equipment can be used to increase the safety, but it then reduces the availability.

Fail safe means that

- no probable fault, including secondary faults, may create a situation in which the train can be driven faster than would have been allowed if the fault had not occurred
- a fault must be detected and cleared so quickly that the probability is very low that another fault will occur which, in combination with the first, can lead to a dangerous situation.

The safety requirement determines how low these probabilities must be. The safety demands on an equipment mean that the design and manufacture become considerably more difficult and expensive.

System JZG 700

JZG 700, the latest ATC system developed by LM Ericsson, transmits a considerable amount of information from beacons in the track, via an antenna on the locomotive, to the evaluation and presentation equipment in the locomotive. The system, fig. 2, consists of

- an *encoder* which senses the signal information
- *beacons* in the track, which transmit the information to the train. The beacons are powered by the passing locomotive
- an *antenna and transmission unit* on the locomotive, for scanning the track and receiving the information from the beacon
- an *evaluation unit*, which, on the basis of information received from beacons, panel, speedometer and braking system, supervises that the driver drives safely
- a *panel* for displaying information to the driver and for feeding information regarding the characteristics of the train to the evaluation unit.

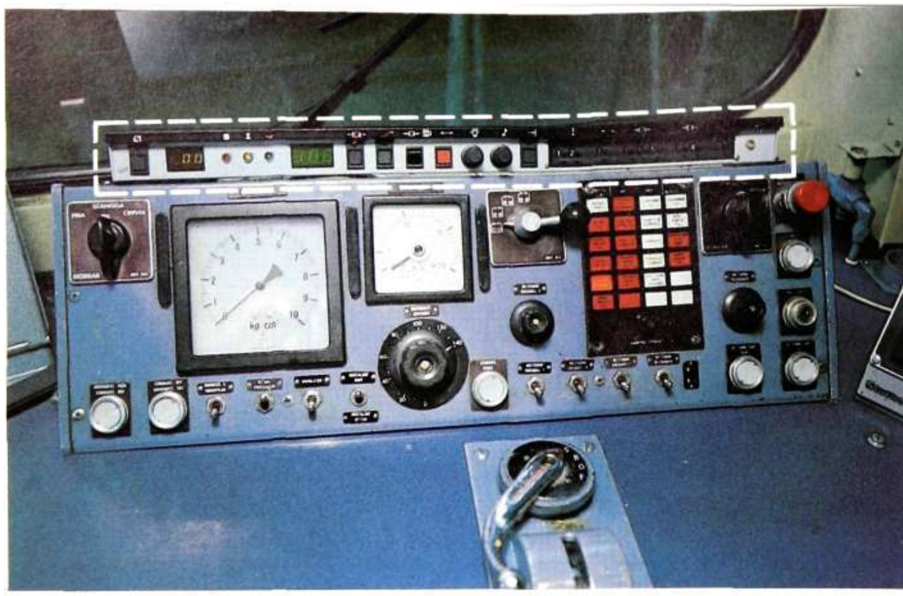


Fig. 5
A driver's panel for the Swedish and Norwegian State Railways. The ATC panel is shown framed in white. The left-hand part of the panel contains digit displays that show the speed limits for the current line section and the next speed restriction. The right-hand part contains thumbwheels for entering data concerning the train, such as the maximum permissible speed for this particular train, its length and the reaction time and the retardation capacity of the brakes. It is also possible to enter whether the train may exceed certain types of speed limits. For example, future special high-speed trains may go through bends at higher speeds.

All units and the communication between them meet stringent safety requirements.

The ATC system is designed for interworking with train radio on the locomotives. The train radio can via the ATC system be provided with information regarding the position of the train and the radio channel number. Via the radio it is also possible to quickly inform the evaluation equipment about changes in the signal information, so that initiated braking can be interrupted. This eliminates the disadvantage of an intermittent system compared with a continuous system.

A fully electronic recording equipment can be connected to the ATC system. It records all relevant information, so that if an accident should occur, it will afterwards be possible to reconstruct the events before the accident.

Adaption to special requests from administrations

Traditionally the railway administrations have different signal aspects. These differences mean that adaption is required between signal and beacon, by means of different encoders. Furthermore the locomotives can have different braking systems, different power supply and different speedometers. In these cases also, adaption is required.

The administrations have different safety regulations and different opinions regarding the information to be provided for the train driver. This affects the panel design and computer program. The program in JZG 700 has a modular structure and is to a large extent written in a high-level language in order to simplify adaption to different requirements.

Function

The speed supervision in modern ATC systems is carried out by means of
- indication of the speed limit
- warning and braking when the speed limit is exceeded, fig. 6
- warning and braking when the driver does not reduce the speed sufficiently when approaching a lower speed limit, fig. 7
- emergency braking if the train passes a stop signal.

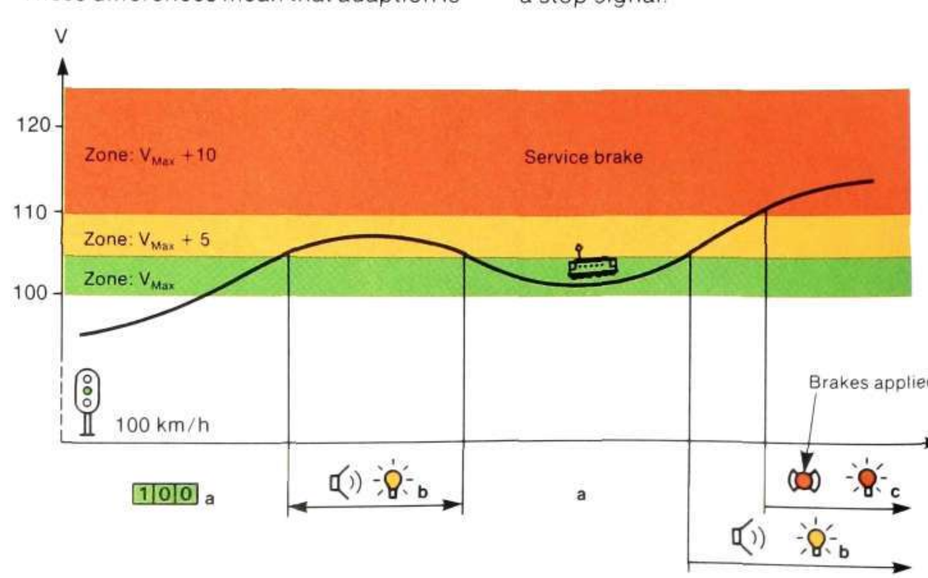


Fig. 6
Warning and braking when the speed limit is exceeded.
a. The display shows the speed limit (V_{Max})
b. Acoustic and visual alarms are given when the speed limit is exceeded by between 5 and 10 km/h
c. Automatic braking is carried out when the speed limit is exceeded by more than 10 km/h. The braking is indicated by a lamp. When the speed of the train is reduced to the permissible level the driver can cancel the braking by depressing a button

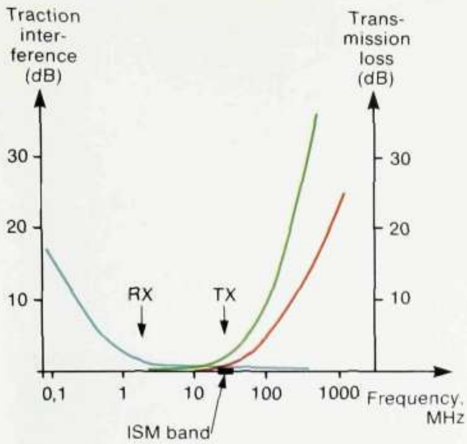


Fig. 8
Choice of frequencies for JZG 700

Relative interference level from the traction current
Attenuation by 10 mm iron ore concentrate
Attenuation by 100 mm water
RX Information frequency
TX Scanning frequency

Advance signals and signs along the line inform the train driver about speed limits on the following sections. Via encoders, beacons and inductive transmission to the locomotive the evaluation equipment receives the same information, supplemented by information regarding track gradient and distance to the beginning of the section with the new speed limit. On the basis of this information and the data regarding the braking characteristics of the train, which were fed in via the driver's panel before the train started, the equipment calculates when the train must be braked in order to slow down to the set speed limit at the beginning of the relevant section. On the Swedish and Norwegian State Railways this information is displayed for the driver when the train is at the normal braking distance (8 seconds before the ATC system intervenes). After that a warning that the train must be braked immediately is given 3 seconds before the ATC system acts. If the driver still does not apply the brakes, this is done automatically.

Track-to-train transmission

The demands made on the track-to-train transmission are severe as regards ability to withstand adverse environment, quantity of information and safety.

The *environmental requirements* are that the system must be able to withstand

- ambient temperatures between −40° and +70° C
- impact acceleration on the beacon up to 300 m/s² (30 *g*)
- blows on the locomotive antenna from bouncing gravel
- oil on the antenna and beacon
- 100 mm water or ice on top of the beacon
- the train antenna covered with ice or snow
- 10 mm iron ore concentrate on top of the beacon
- electrical and magnetic interference from the locomotive
- interference from radio transmitters.

These environmental requirements affect the choice of material and transmission frequency. Low frequencies suffer more from interference from the locomotive traction system. In addition low frequency means large dimensions. The choice of higher frequencies is mainly limited by the effects of water, dirt and ore on the beacons, fig. 8.

The telecommunications administrations accept the use of the internationally standardized ISM band at

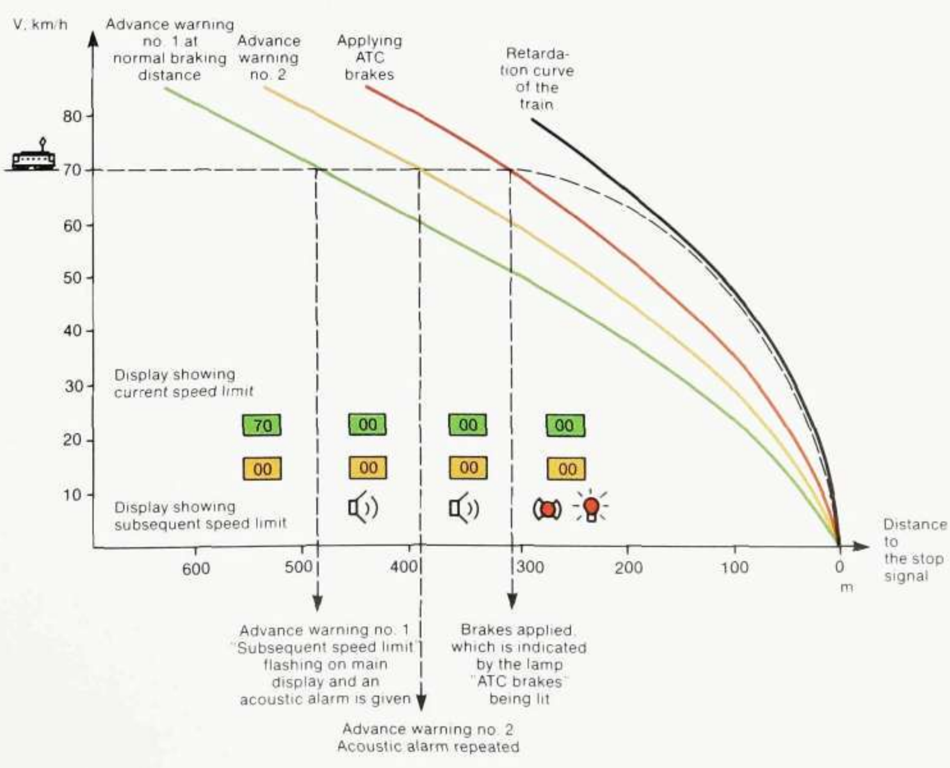


Fig. 7
The function of the ATC system on the Swedish state railways for a train at 70 km/h which approaches a stop signal without the driver applying the brakes.
S is the distance between the point where the ATC system intervenes and the beginning of the section with lower speed limit
S=the advance warning distance + the brake application distance + the braking distance

$$S = t_f V_T + t_b V_T + \frac{V_T^2 - V_M^2}{2b}$$

V_T The speed of the train
V_M The speed limit (in this case 0 km/h)
t_f Advance warning time
t_b The appplication time of the brakes
b The retardation of the train with full braking power, adjusted for track gradient and bad track conditions

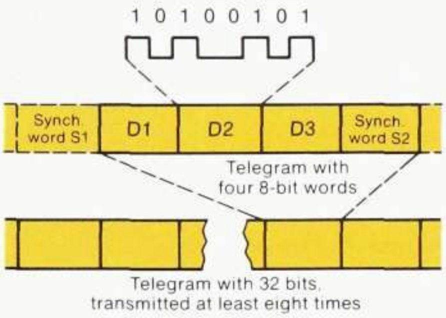


Fig. 9
The quantity of information per message. The message from a beacon consists of three eight-bit data words, D_1, D_2 and D_3, and a synchronization word, S_1 alternating with S_2. The *message must be transmitted at least eight times* while the locomotive travels over the beacon.

27 MHz for the scanning signal from the locomotive to the beacons. The frequency is at the upper limit for what is called inductive transmission.

The level of the signal from the beacon to the locomotive is so low that there is no risk of it causing interference. The locomotive motors cause more interference than this signal. A frequency of 4.5 MHz was chosen for this direction to avoid any disturbance from radio transmitters.

The *quantity of information* which it must be possible to transmit to the locomotive corresponds to more than 3000 different messages. This is achieved by sending 3 words, each with 4 information bits, from each beacon. Four redundancy bits per word are added in order to reduce the risk of errors. The 8-bit words thus obtained are encoded so that 4 bits in a word must be wrong if it is to be possible to mistake one code word for another.

In order to reduce the error risk further, the equipment in the locomotive will only accept messages that have been identical at least four times of the eight times it has been received during the passage over a beacon. Each three-word message is preceded and followed by different eight-bit synchronization word. These precautions mean that the risk of a message being misinterpreted is negligible.

As can be seen from fig. 9, more than 256 bits must be transmitted while the locomotive passes over a beacon. With train speeds of up to 300 km/h and a beacon and antenna size of only 0.5 m a transmission rate of 50 kbit/s is required.

The *safety requirements* demand that beacons must be detected and that it must be impossible to misinterpret a message. The risks of misinterpretation have already been discussed. The beacon is designed so that no individual fault or probable combination of faults can lead to the beacon transmitting a less restrictive message than the correct one.

The beacons are installed in groups of not less than two. If one beacon develops a fault the driver of a train that passes this beacon receives an alarm. The equipment in the locomotive checks that the beacon groups are complete and that the distance between adjacent groups is correct.

For reasons of safety and maintenance the transmission of information to the train has been made independent of batteries etc. in the track equipment. The energy for the beacon logic and the sig-

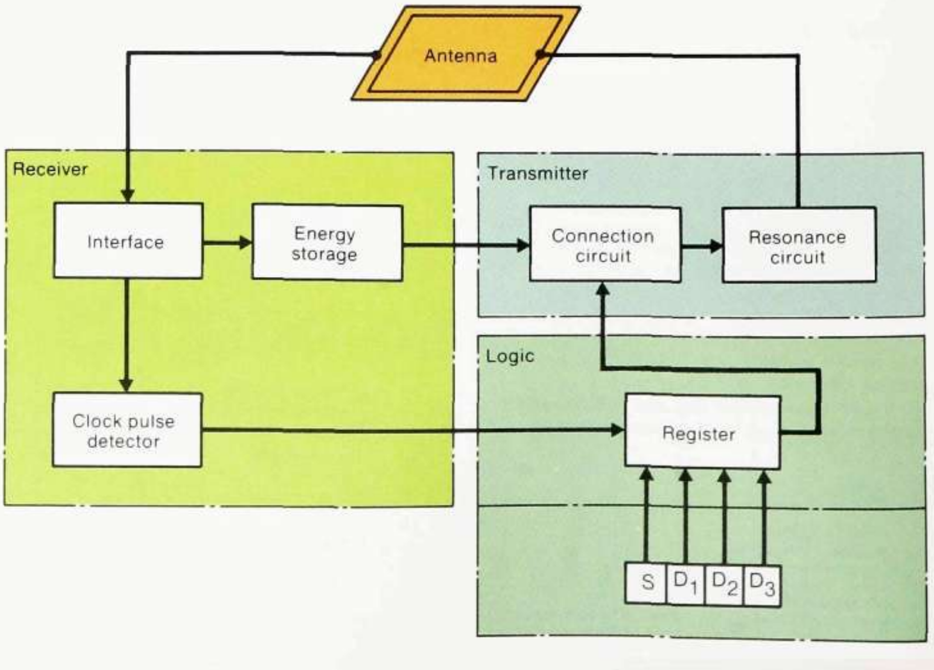


Fig. 10
A block diagram of the electronics in a beacon

Fig. 11
Antenna

The ATC system of the Swedish State Railways can transmit any of the following numbers of messages from the beacon to the antenna:

– current speed limit from main signal	14
– subsequent speed limit from advance signal, i.e. the *speed the train must keep at the next main signal*	14
– speed limit from speed limit signs (5 causes and 42 levels)	210
– subsequent speed limit from precaution signs, i.e. the speed the train must keep at the next speed limit sign	210
– distance between advance signal and main signal or between precaution sign and speed limit sign	210
– track gradient	15
– signal identity	2048
– radio channel number	196

nalling back to the train is transmitted from the train. The energy for the encoder electronics and its control signals to the beacons is taken from the power feeding to the lamps in the signals that the encoder is sensing.

Beacon design

Fig. 10 shows the block diagram of a beacon. The scanning signal from the locomotive is received by the receiving loop in the beacon. The scanning signal consists of a 27 MHz carrier, interrupted by 50 kHz clock pulses. The energy content of the signal is stored and the clock pulses are filtered out. The receive side of the beacon contains an energy output and a clock output.

Every clock pulse shifts the contents of a register in the beacon logic one bit forward. The register contains the message to be sent to the train. When the shift register output contains a zero the energy stored in the receive side of the beacon is fed out to a resonance circuit, whose inductance consists of the transmitting loop. The resonance circuit starts to oscillate at 4.5 MHz with decaying amplitude. No energy is fed to the resonance circuit if there is a one on the shift register output.

When 32 bits have been shifted out in this way, new information is read into the shift register in parallel. Fixed information, such as synchronization words and information regarding preset speed limits and distances, is obtained from strapped connections in the beacon. Information concerning signal-dependent speed limits is obtained from the encoder.

The beacon consists of a sheet of glass fibre armoured plastic with receiving and transmitting loops embedded in the rim. The electronic components are mounted on a printed circuit board placed in a box underneath the sheet. The printed board assembly is surrounded by a filling that protects the components against damp, reduces vibrations and prevents cracking by frost. A life of 40 years has been aimed at when designing the beacon. The beacons are only 22 mm high so that they are not damaged during snow clearing and other work on the track. Their width is 400 mm and the length 536 mm.

Transmission equipment in the locomotive

The carrier is generated in the transmitter printed board assembly in the evaluation equipment. The carrier is modulated by 50 kHz clock pulses which cut off the carrier for a few microseconds. The antenna equipment contains a power amplifier stage for the output signal. The antenna is shown in fig. 11.

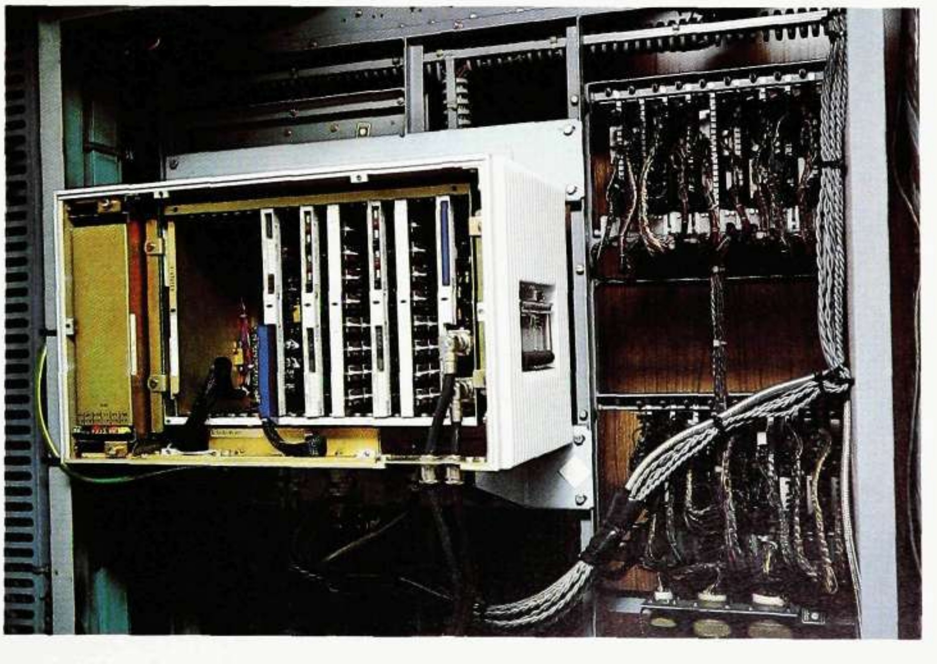


Fig. 12
An evaluation unit, mounted in a driver's cabin. The unit consists of a power unit and transmission, processor, data storage and interface units in the form of printed board assemblies. They are placed in a cabinet having the dimensions 400×300×325 mm. The problems with interference from the locomotive have been overcome by galvanic insulation and filtering of all incoming and outgoing conductors at the input to the evaluation unit. Communication with the panel takes place over two-wire lines, with data sent in series form.

The 4.5 MHz signal from the beacon is received by two loops in differential coupling in the antenna. This coupling suppresses the 27 MHz signal from the send loop, which is placed between the two receive loops. It also suppresses radio interference.

In order to ensure that the antenna and transmission function satisfactorily they are frequently tested by means of a test beacon placed in the antenna. This beacon can never be more sensitive or send a stronger 4.5 MHz signal than the faintest beacon which the equipment must be able to detect. The test beacon is activated every 50 ms by the computer in the locomotive. An alarm is given if no signal is then detected.

The evaluation equipment and its safety level

The evaluation equipment, fig. 12, has to process so much information that computers have to be used. Hitherto the use of computers in safety systems has been restrained, although development and experiments have been carried out in many countries. Solutions have been sought that make the systems safe in spite of the fact that components in the computers can develop faults. The fault types that must be considered in a computer system are

- hardware faults, such as random component faults, systematic component faults and interference
- software faults.

Much of the experience gained from relay and electronic systems without computers can be drawn upon to clear hardware faults in computer systems.

Two independent channels are often used for the processing of information in order to detect any random component faults. Checks that the results are the same are made at the channel outputs and at suitable points in the channels. If this checking is made frequently and is extensive enough, the risk is negligible that both channels develop the same, independent fault without it being detected.

Complex components sometimes contain systematic faults, i.e. faults that occur in all circuits of a certain type or in a certain production batch. For example, a certain combination of data can cause a functional fault since the component may be pattern sensitive. The risk of such faults affecting the function is small enough to be acceptable as regards the availability requirements for most systems, and the components are therefore sold in spite of the faults. In safety systems such faults must be rendered harmless.

In safety systems it is also important that dangerous output data are not produced even outside the specified temperature range, and thus faulty functions must also be considered in these areas.

Systematic component faults can be detected by designing the two calculation channels differently, or by not using them in the same way. Differences between the channels also mean that the results obtained will be affacted in different ways by any interference.

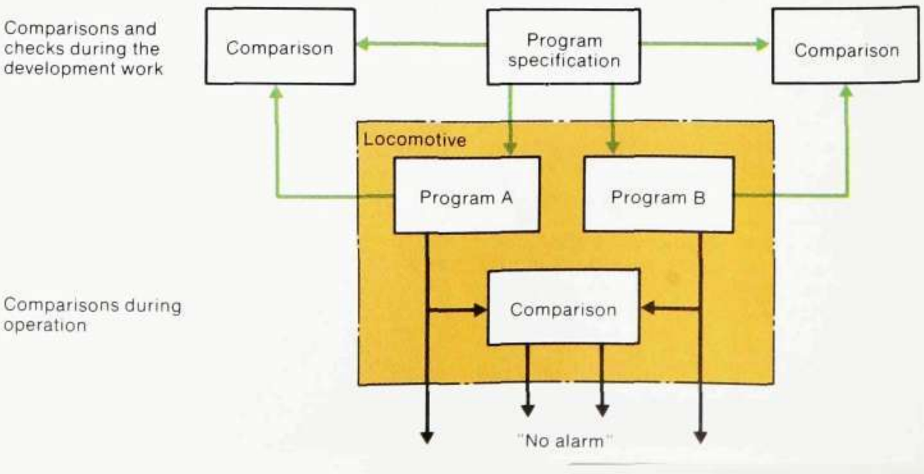


Fig. 13
The two-program method means that
- tests and checks are carried out at the specification stage in order to find any faults before the work is divided between the two teams of programmers
- each program is made so safe that the probability that both programs have the same, independent fault is negligible
- the interdependency of the two programs is at a level where checks and tests can be carried out
- faults in the programs are detected by comparison
- all possible cases are tested when they occur

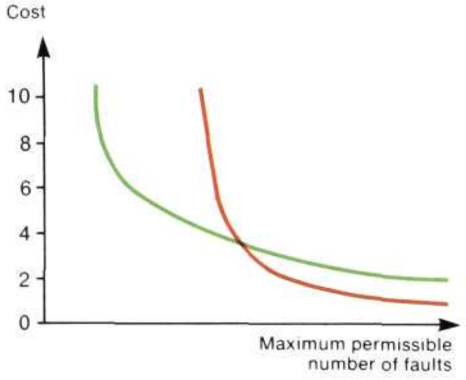


Fig. 14
The program cost as a function of the maximum permissible number of faults for one and two programs
2 programs
1 programs

Fig. 15
Installation.
The Swedish State Railways have made great efforts to get the ATC system installed and taken into service as quickly as possible. Several aids have been developed to simplify the installation in the track. The picture shows one of the three special vehicles that plough down the cables which connect the encoders and the beacons

Of all the possible types of faults in a computer system, software faults are most difficult to clear. It is well known that it is practically impossible to design faultless programs unless the programs are very simple. It is even more difficult to prove that they are faultless.

However, it is fairly easy to make a program function properly in normal situations, since any faults are quickly detected during functional tests in the real environment and during simulations. But safety systems require that the program functions properly even in abnormal situations. The safety requirements for ATC systems are about six powers of ten more stringent than the availability requirements.

Since there is no method or combination of methods that makes the program faultless, the system design must be such that residual program faults do not have any dangerous effects.

The method chosen by LM Ericsson for the programming of the ATC system is based on redundancy programming. Two independent programmer teams each design and test a program version that they make as safe as possible. When the two programs are executed, an alarm is given if any intermediary result or the final result differ, fig. 13.

Both these programs and the comparison program are stored in the equipment, and during the operation the programs are tested against each other for every combination of input data that is used. The ATC system is too complex to allow testing of all possible combinations of input data before it is put into operation.

The method using two programs means that any remaining faults are harmless. The faults that remain concern only very odd and abnormal situations, and thus they do not affect the availability of the system.

Installation and putting into operation

LM Ericsson designs and manufactures encoders, beacons, antennas, evaluation units and drivers's panels for ATC system JZG 700. In Norway and Finland, the countries that have most recently ordered ATC, LM Ericsson is the main contractor for the system and supplies all equipment. In Sweden and Denmark LM Ericsson supplies all ground and transmission equipment, whereas the majority of the evaluation equipment and panels are supplied by another manufacturer.

However, to put an ATC system into operation requires more than just the delivery of the described equipment. The input signals to the system must be generated and the output signals from the system must be dealt with. The equipment must be installed. The maintenance organization must be prepared to take on the ATC system. The train drivers must be trained. The cost of the auxiliary equipment and the work connected with the installation of ATC is approximately of the same order as the cost of the ATC equipment itself.

The Swedish State Railways calculate that the installation of the 1200 locomotive equipments will take about three years. The installation is contracted to different installation firms.

The State Railways themselves are carrying out the installation of the about 11 000 encoders and 40 000 beacons. The work is expected to take five years, but so far it has gone better than planned. Great efforts have been made to ensure that the planning and installation of the ground equipment proceed smoothly and efficiently without any of the safety aspects being neglected, fig. 15.

In Sweden, area after area are taken into operation and locomotive after locomotive is put into service as soon as the installation work is completed. All commuter train traffic in the Stockholm region will be equipped with ATC in 1981. The lines Stockholm–Malmö (south Sweden) and Stockholm–Gothenburg (west Sweden) will also be completed in 1981.

The first lines in Norway will be taken into service in 1981, in Denmark in 1983 and in Finland in 1984. Outside the Nordic countries an early variant of the system was put in operation in Taiwan in 1979.

Reference

1. Andersson, H.S.: *Railway Signalling Systems.* Ericsson Rev. *57* (1980):4, pp. 118–123.