Optical Transmission Link in ATC Systems

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Ericsson's automatic train control system, JZG 700, has been described previously in Ericsson Review[1]. In this system information is transmitted from information points, beacons, on the track to antennas on the locomotives. Normally the beacons receive their information from railway lamp signals via multi-wire electrical cables. An optical transmission link has been designed for the system for use in the cases where the distance between the signal and the beacon is so large that the ordinary electrical cable cannot be used because of interference from the traction current.

The authors describe the need for and demands on such a transmission link, the design of the new link, the design of the optical cable and various possible ways of installing the cable.

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The Nordic Railway Administrations are now installing an automatic safety system which will control the speed of the trains (ATC). The system chosen is manufactured by Ericsson and designated JZG 700. It consists of

- a transmission system with inductive transmission of data from the track to the locomotive at fixed points, beacons, placed along the track
- a microcomputer-controlled locomotive unit with a driver's panel for supervision of the speed of the train and with automatic braking if the train speed is too high.

Descriptions of the system have been published in earlier issues of Ericsson Review[1,2].

The supervision of train speed is based on various data, such as information from the lamp signals along the track. This information is transmitted to the beacons, fig. 1. The beacons also include fixed, programmed information. Both types of information are transmitted to the passing locomotives.

The information from the lamp signals to the beacons can be transmitted over an electrical or an optical transmission link.

The electrical link contains an encoder which scans the lamp currents in the light signal. The encoded data are transmitted in a multi-wire cable. The link has a simple design, requires little current and contains few circuits, which gives it high reliability. It is suitable for most installation cases.

The disadvantage of the electrical cable is that the transmission distance is limited to approximately 300 m because of interference from the traction network,

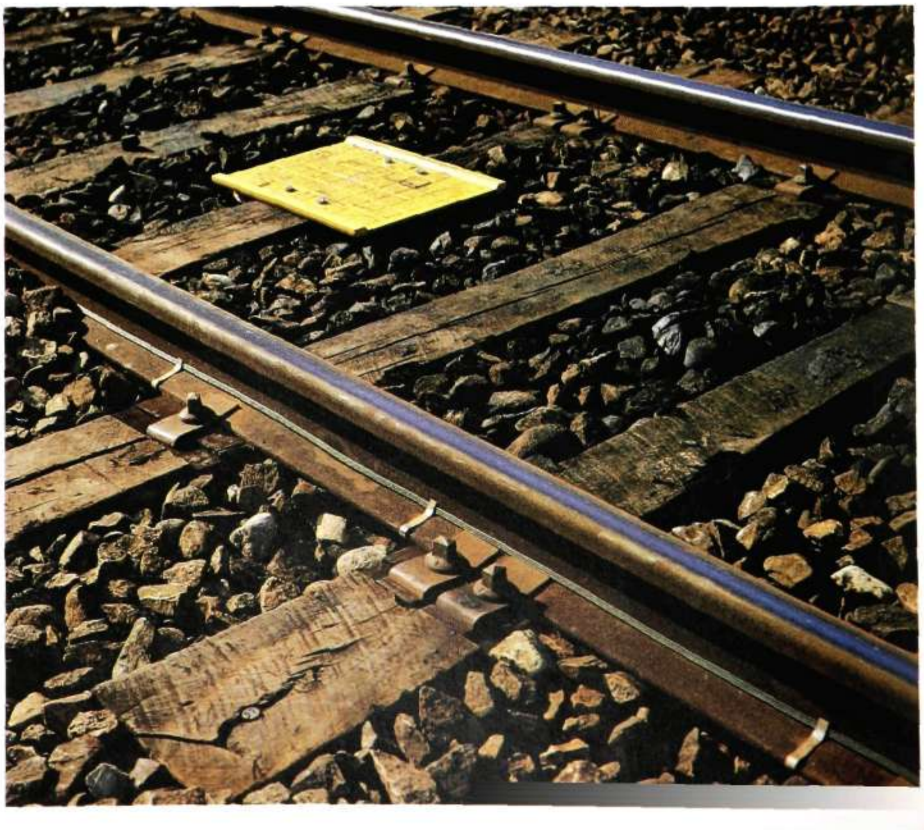

Fig. 1
Optical cable for transmitting information from the signal to the beacon

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short circuits in the network and earth faults.

An optical transmission link used for transmitting the same information does not limit the distance in the same way. Fig. 2 shows a comparison between an electrical and an optical fibre link.

Optical transmission link: system and applications

The optical system comprises:
- optical transmitter
- optical receiver included in the beacon
- optical single-fibre cable, including installation material
- splicing equipment for the fibre cable
- test instruments for installation and maintenance
- optical fibre connector.

The system characteristics can be summarized as follows:
- transmission distance < 3 km
- the transmitter is powered from the lamp signal or by a separate source
- the transmitter is matched to the existing encoder output towards the beacon
- the transmitter is adapted to the construction practice in existing buildings for signalling equipment.

The environmental requirements are severe, see table 1.

One unique feature of the system is that only one optical fibre is used and that the synchronization of the signal from the optical transmitter with the continuously transmitted scanning signal from the locomotive takes place in the beacon. Synchronization could have been obtained by transmitting the synchronization pulses from the locomotive via the beacon to the transmitter, but that would have required another fibre in the cable and twice as many transmitters, receivers and fibre splices.

The cable can be installed in different ways. One way which has been found to be successful is to place the cable in the waist of the rail. However, running the cable along the track and in the rail waist is not an innovation. There are ATC systems which use electrical cable installed in this way for continuous transmission of safety data between the track and the locomotive. Figs. 3 and 4 show the structure of the new optical link.

Design

OPTICAL TRANSMITTER

The transmitter receives data in parallel form, as three eight-bit words (X, Y, Z). The words can be controlled by relays, ATC encoders or a fixed strapping. The parallel/series conversion is carried out and a synchronization word is added, which gives a 32-bit telegram. The conversion equipment is designed in accordance with the same principles as the equipment in a beacon controlled via an electrical cable.

Table 1
Environmental requirements for the optical transmission link

	Transmitter	Beacon	Cable
Temperature, °C	−40-+70	−40-+70	−30*-+80
Shocks, m/s²	50	300	420
Relative humidity, %	10-95	10-100	10-100

* Temperature requirement for field trial systems

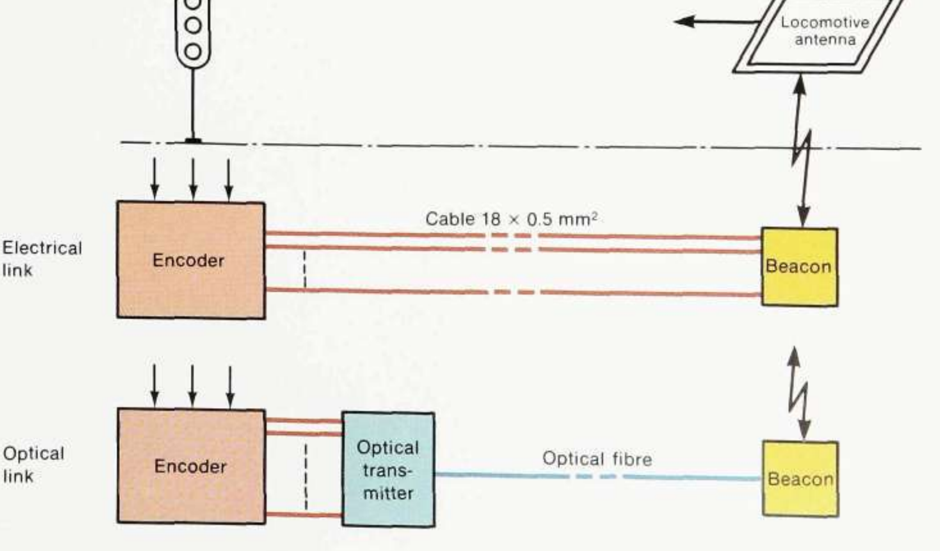


Fig. 2
A comparison between an electrical and an optical fibre link

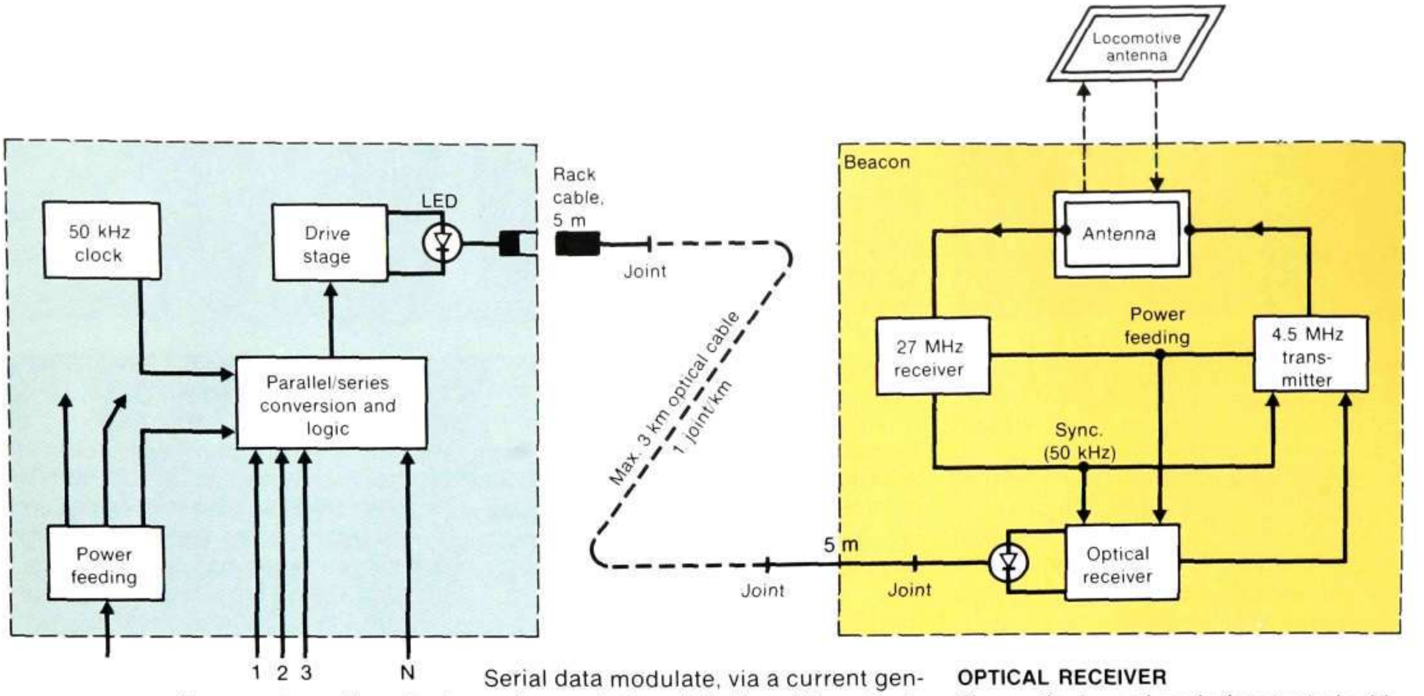


Fig. 3
A block diagram of optical fibre link equipment

Serial data modulate, via a current generator, an infrared light-emitting diode with short pulses. The LED is optimized for low power consumption, good coupling to the fibre and long life. The logic circuits are controlled by a 50 kHz clock, which gives a bit rate of 50 kbit/s for the transmission to the beacon. The transmitter can be power fed by the encoder, which has a limited supply of power (approximately 1 W).

Technical data for the optical transmitter, fig. 5, are:

– Wavelength	850 nm
– Pulse width	3 μs
– Optical pulse power	>25 μW
– Possible power reduction	10–15dB

The light-emitting diode is alight approximately 7% of the time (varies slightly with the information content), which means that 25 μW pulse power corresponds to approximately 1.8 μW mean power. The low mean power ensures that there is very little probability that the optical power of the LEDs will decrease with time. The reliability is therefore high. The output power can be reduced further if the fibre route is short.

OPTICAL RECEIVER

The optical receiver is integrated with the rest of the beacon electronics. The received serial data are detected in a sensitive optical input stage and are converted in an asynchronous/synchronous converter, which is controlled by a clock signal. The clock signal, like the power feeding for the receiver and other electronic circuits in the beacon, is obtained from a 27 MHz carrier, which is transmitted by the equipment in the locomotive when it passes over the beacon. The output from the optical reciver modulates a 4.5 MHz carrier which transmits data in serial form from the beacon to the locomotive.

The optical receiver, fig. 6, meets the following requirements:

- low power consumption, 10 mW (1 mA, 10 V)
- correct data detection 0.5 ms after the beacon has received the feeding voltage. A high-speed train can pass the beacon in less than 6 ms
- a high degree of sensitivity, the sensitivity limit must be better than 5 nW pulse power, which corresponds to approximately 0.4 nW mean power
- a large dynamic range for detecting optical signals with a pulse power of

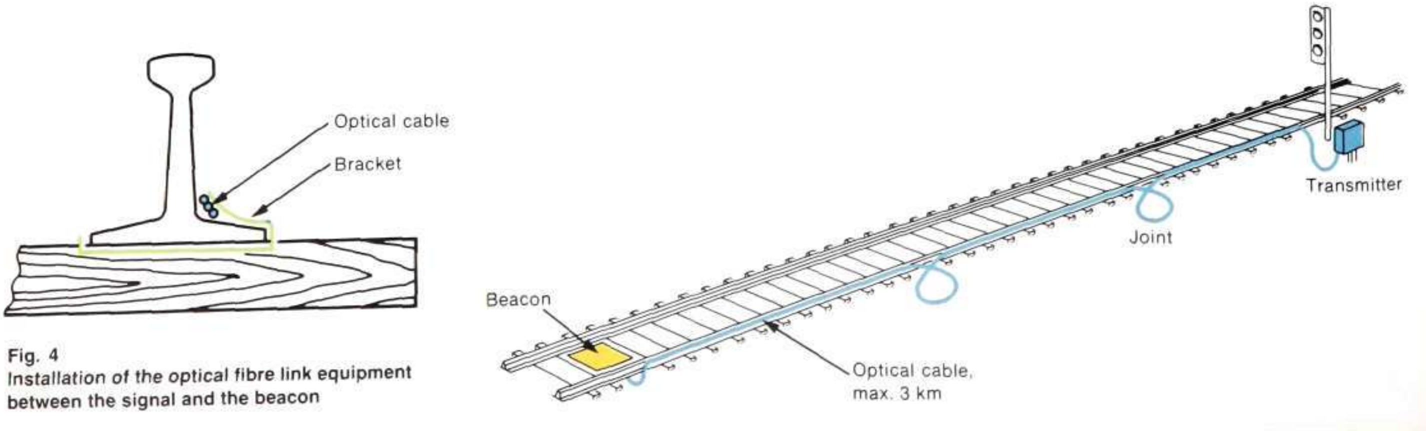


Fig. 4
Installation of the optical fibre link equipment between the signal and the beacon

Fig. 6
Beacon with the optical receiver

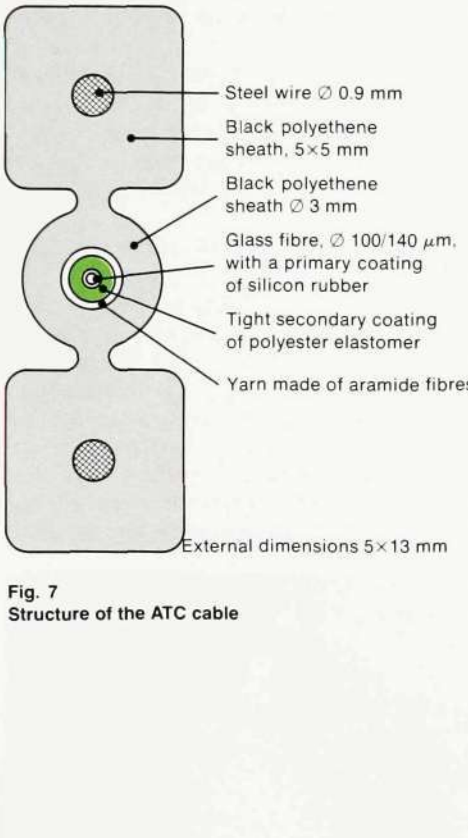


Fig. 7
Structure of the ATC cable

between 5 nW and 50 μW (corresponds to a 10 000 times change of signal amplitude). The receiver must quickly adapt to instantaneous changes in amplitude in order to meet the second requirement above

- synchronization of the input signal to the beacon with the clock frequency of the locomotive equipment
- ability to withstand large variations in climate.

OPTICAL FIBRE CONNECTOR

The optical connector matches the fibre cable to the light emitting diode in the transmitter. Two types of connectors have been tried in the system. Moisture-proof mounting of the LEDs and the fixing devices was one of the design aims. The results of temperature cycling tests in high humidity show that the function is not impaired even in severe cold.

The optical fibre connector constitutes a test point for the transmitter power and the digital data from the transmitter, and also a testpoint for the fibre cable and beacon characteristics.

CABLE DESIGN

Fibre

The transmission medium is a double crucible (DC) glass fibre for industrial applications. The Swedish cable manufacturer Sieverts Kabelverk develope and manufacture fibre and fibre cables[3].

The DC fibre has good transmission characteristics for optical signals. The attenuation is 7–9 dB/km at a wavelength of 850 nm.

The fibre consists of a multi-component glass core with a high refractive index, covered with a glass cladding having a lower refractive index. The cladding also contains small quantities of various additives which greatly increase the ability of the fibre to withstand the chemical effects of the atmosphere. The additives also increase the mechanical strength.

A primary coating of silicon rubber protects the fibre against microcracks and dust particles. The coating is applied when the fibre is drawn. The strength is tested during the manufacture by the whole length of fibre being elongated by 0.5–1%. A soft but tough secondary coating, a large diameter and a large numerical aperture (NA) are the main factors that prevent any increase in attenuation as a result of the cabling and the laying of the cable. The increase in attenuation caused by the connection of the fibre to the light source and any splicing is also kept low.

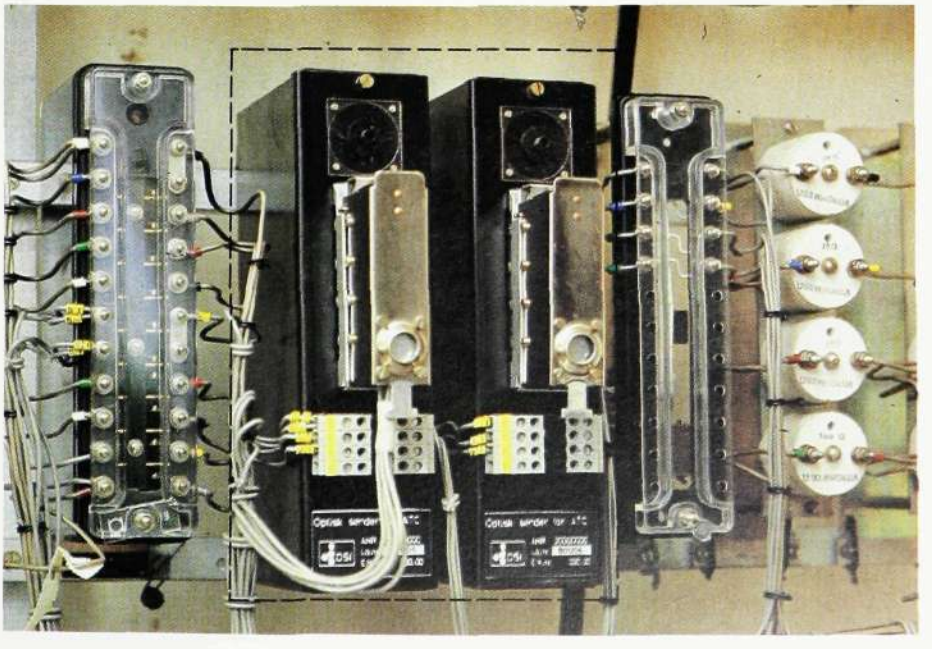


Fig. 5
Two optical transmitters

Fig. 8
A bracket holds the cable in place

Cable

A flat cable structure, fig. 7, was chosen because of the special laying method. The fibre with is primary coating is given a secondary, extruded coating consisting of an extremely durable plastic (polyester elastomer). Aramide yarn is then stranded round the fibre, followed by a layer of polyester tape. Finally the cable body is covered with a sheath of black polyethene. In this process the fibre with its protective layers is fed between two parallel steel wires through a nozzle, where the black polyethene is extruded to the desired profile. The wires take the strain during the cable laying and also any strain caused by temperature variations. The sheath gives protections against mechanical damage and the environment. The centre part of the cable, which contains the glass fibre, is smaller than the two outer parts, which therefore protect the centre against wear.

The ATC system also required a lighter, more flexible cable. It was to be used for wiring in the beacon and in racks and shelves on the transmitter side. This cable has the same structure as the cable body in the flat cable and a sheath of durable polyurethane.

Cable laying

The normal way of laying a cable is by means of burying. Cables for railways can either be laid in the roadbed or in cable conduits by the side of the track. In the first case the cable is usually ploughed in, and only short distances have to be dug by hand.

Other methods can be used for laying optical cables. There are two alternatives, both of which utilize the insensitivity of the fibre as regards traction current:

- running the cable along the rail, with bracket fastening, fig. 8
- running the cable on a pole line with its own suspension wire or on the return wire for the traction current.

The advantage of the first method is that the digging cost is avoided. This cost is high, particularly if much hand digging has to be done. However, other costs are incurred instead, such as the alteration cost when rails are changed and, possibly, increased maintenance costs for damaged fibre cables. The cable must be laid in such a way that mechanized track maintenance will not be prevented by the cable, nor affect it.

Fig. 9
Splice fusing unit with a fixture for fibre with secondary coating or a small round cable

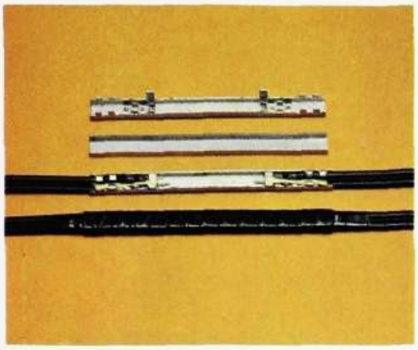


Fig. 10
Joint sleeve

In the case of the second alternative using suspended cable, consideration must be paid to the climatic conditions (wind, cold, snow etc.) that make maintenance more difficult. For example, what action could be taken in the case of a break in the fibre if it is not possible to disconnect the traction current because of the railway traffic? In the autumn of 1981 a trial with suspended cable was started on a cable section in Stockholm, Sweden. The cable was suspended from the return wire for the traction current. The trial results have yet to be evaluated.

In Denmark a technical/economic investigation was held which resulted in a decision to carry out a field trial with the cable laid in the waist of the rail and fastened with spring steel brackets, figs. 4 and 8. The bracket is installed first, then the cable is run out along the rail and is finally inserted under the bracket. The installation can be carried out without any interruption in the railway traffic if guards are posted.

At exposed points, for example rail joints, the cable is protected against wear by means of a piece of polyethene tubing. If the metallic conductors in the cable have to be insulated galvanically, the cable can be jointed by cutting the two steel wires and encasing the joint in epoxy resin to maintain the original strength.

Another way of fastening the cable to the rail is by means of so-called stud brazing. A special "brazing gun" is used to braze a cable clamp to a suitable spot in the waist of the rail. Both the brazing and the cable laying can be carried out more or less automatically from a rail vehicle. This method is approximately 3–4 times faster than the previous method and gives better friction against cable movements. Field trials have shown that the cable may other-wise move as a result of vibrations from trains on tracks with one general direction of traffic (double track).

The installation can be simplified by manufacturing custom-made cables with the desired length and factory-mounted connectors. Such cables should also be used when immediate repairs are necessary.

Jointing

A special jointing method has been developed that is suitable for the cable profile, the laying method and the severe environmental requirements.

The first stage in the jointing is to prepare the cable ends, after which they are placed in a fixture in a splice fusing unit, fig. 9. The glass fibres are fused together by means of an electric arc.

The melting temperature of DC fibre is relatively low since it consists of multicomponent glass. In order to obtain a good splice the energy must be concentrated at the fibre ends and the fusing time must be fairly short (0.15 s). Prefusion is not required. The arc is ignited with a small gap between the fibre ends (5–10 μm). The gap is closed by the thermal expansion of the fibre. The splice loss between identical fibres is less than 0.20 dB. This fusing method has been described in detail previously[3].

The spliced fibre is placed in a stainless steel sleeve, fig. 10, with a small excess of fibre so that the splice is not stretched. The steel wires and the aramide yarn are then fixed to the sleeve by means of a clamping tool. The sleeve is

Fig. 11
Jointing cable in the field

Table 2
Trial routes and evaluation

Trial routes	Denmark				Sweden
	A	B	C	D	Stockholm
Structure					
Length (m)	10	3 000	520	1 683	1 000
Number of fibre joints	1	4	2	3	1
Number of fibre connectors	1	1	1	2	
Complete ATC system	+	+	+	–	–
Evaluation					
Trial runs with ATC trains	+	+	+	–	–
Recording of short-term and long-term stability	–	+	–	+	+
Track maintenance	+	+	+	–	–
Change of rails (planned)	–	–	–	+	–

filled with vaseline and closed with a stainless steel lid and a shrunk-on tube. The completed cable joint can withstand temperature variations and also water, ice and mechanical shocks. The joint can be placed direct on the rail or buried by the side of the track.

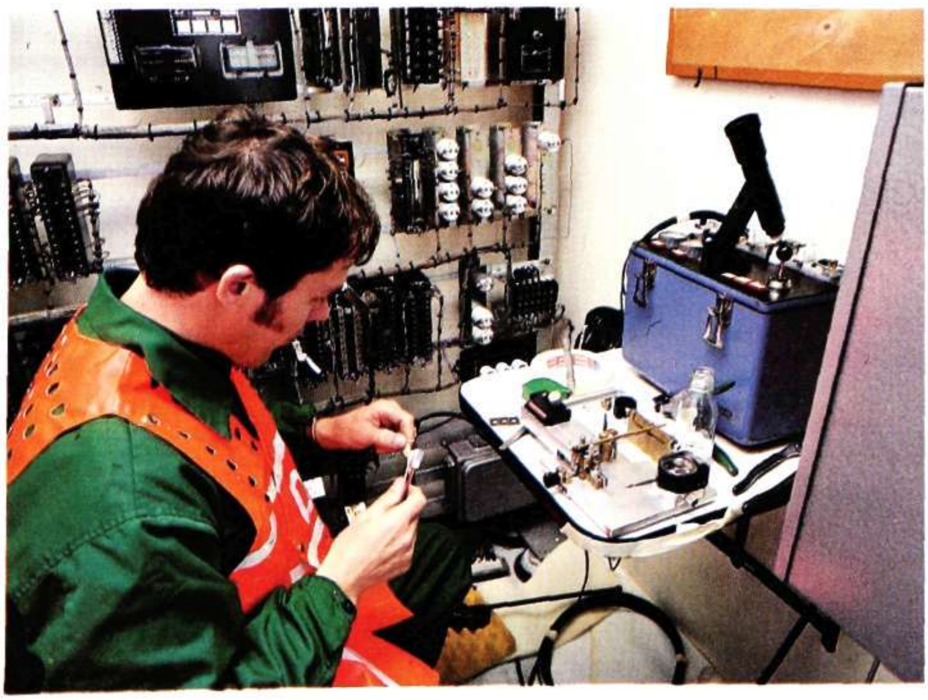
It takes approximately 30 minutes to complete a cable joint. Great care must be taken to arrange the work site so that the shortest possible work and preparation times are obtained.

Measuring methods in the field, fault localization

Cable checks can be carried out in connection with the jointing. Both cable and jointing losses can be determined with a simple transmission measurement. The test transmitter must be stable and have a well-defined light input to the fibre. Both the test transmitter and the test receiver are battery operated and are equipped with cable and fibre sockets for easy connection.

The present system design does not require bandwidth measurements on installed cables.

Fig. 12
Jointing fibre cable in a building for signalling equipment



The installation time can be reduced by making measurements only on jointed cable sections.

Fault localization, for example if there is a break in the fibre, is carried out with the aid of a time domain reflectometer (TDR). Breaks can then be found with an uncertainty of only ±5 m.

When the installation testing of the cable has been completed, the optical output power of the transmitter is measured. The system margin can be checked by placing a variable optical attenuator between the transmitter and the cable. A test instrument records the function of the beacon. The optical output power is reduced until functional errors occur. The system margin is calculated on the basis of the difference in output power from the optical transmitter and the optical attenuator.

Completed field trials

Stockholm, Sweden,
The Swedish State Railways provided a trial route at Duvbo, near Stockholm, for testing the installation method and investigating whether passing trains would disturb the transmission in the glass fibre. This particular route was chosen because it had a high traffic volume and was due for maintenance. Large rail movements could therefore be expected when trains passed.

In January 1980 a 1 km long cable was run in a loop along the rail. The cable ends were connected to recording equipment, which continuosly monitored the cable and which was sensitive to rapid changes in attenuation caused by, for example, a passing train. Such interference will cause modulation, which if significant, may deteriorate the transmission performance. The recording continued until July 1980, when the trial had to cease because the rails on the route were to be changed. No attenuation changes were obtained with a threshold level of 1% and an upper frequency limit of 10 kHz. In other words the result was favourable for further trials with the cable.

Denmark
In October 1980 a large-scale field trial

was started by the Danish State Railways, Dansk Signal Industri, Ericsson and Sieverts Kabelverk AB.

Three optical link systems with a total of 5 km of cable were supplied for the trial route. The aim of the trial was to study the effect on the systems of the climate, train traffic and maintenance.

During the installation attenuation measurements were carried out before and after the cables were jointed. A total of 10 joints were made. Five were made in buildings for signalling equipment situated by the side of the track, fig. 12. Using a tent for protection the flat cable was jointed in five places. The joints and the extra cable at the joints were buried. System testing was carried out after the cable, beacons and encoders had been installed, table 2.

Another system test was carried out in June 1981. The output power of the light emitting diodes had not decreased, and the sensitivity limit of the beacon receivers had not changed.

When repairing a damaged cable on route C, a cable joint was mounted in the waist of the rail. This test mounting proved satisfactory.

Long-term recording of changes in attenuation was carried out on the high-traffic route D during November 1980 and June 1981. The changes were insignificant and no faults were recorded.

In August 1981 route B was treated with a machine that tamps down the crushed rock on the roadbed, with simultaneous recording of the attenuation. No changes were observed with an alarm threshold of 0.5 dB and a time constant of 0.5 ms. The attenuation on the route was 31.1 dB at the time of installation, 31.5 dB before the roadbed treatment and 31.2 dB after. A cable joint was removed and tested in a laboratory. No deterioration could be detected.

A train equipped with test equipment for the ATC system travels routes A, B and C regularly. No faults have been reported.

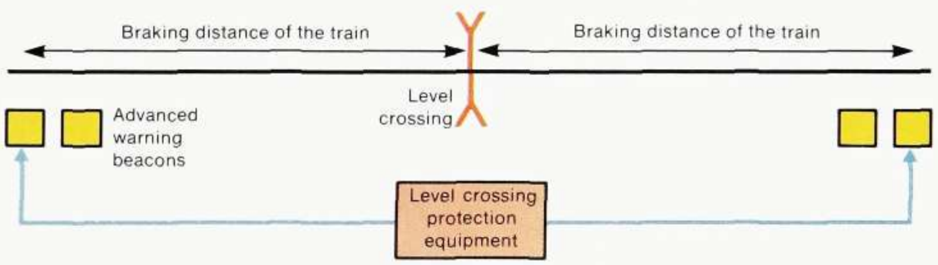


Fig. 13
System application for level crossings
— Optical cable

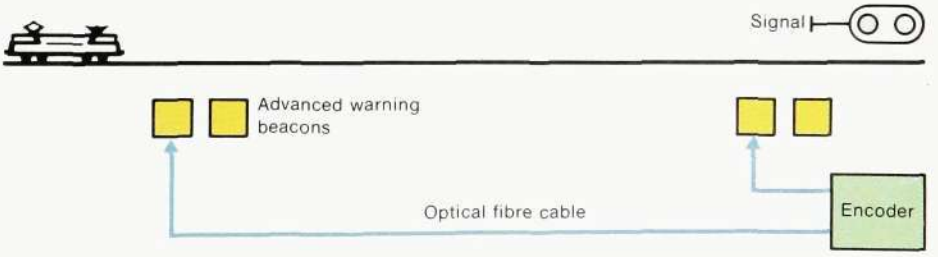


Fig. 14
System application for additional advanced warning

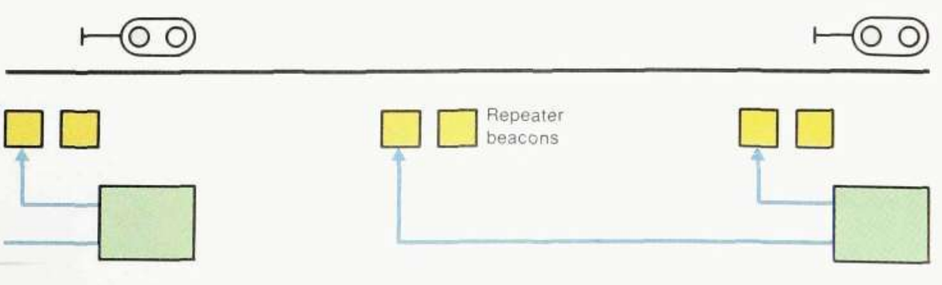


Fig. 15
System application for beacons placed between signals

Technical data for the fibre cable

Number of fibres	1
Type of fibre	Step index
Core/cladding glass diameter	100/140 μm
Numerical aperture	0.30
Attenuation (850 nm)	<10 dB/km
Pulse dispersion	20 ns/km
Minimum bending radius	100 mm

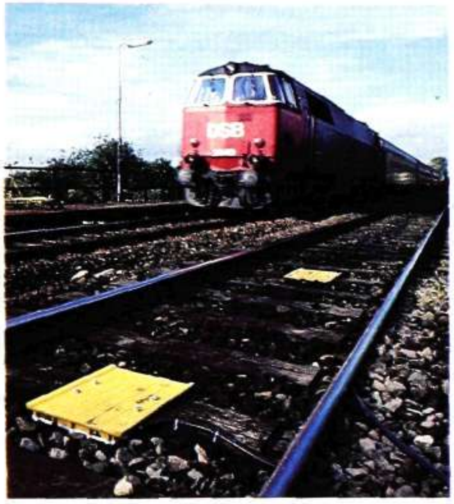


Fig. 16
Optical fibre beacon installed at a beacon site which contains two beacons

System aspects

The link between the light signal and the beacon must be at least of the same quality as the other equipment in the ATC system so as not to reduce the performance of the system. The system has therefore been designed with a high level of both safety and reliability. For example, the link is designed so that if there is a break in the cable or an electrical fault occurs, the beacon will transmit a bit pattern to the locomotive which shows that the beacon is faulty. In this way the fault cannot affect safety, and the fault can be recorded and located.

A data bit must be inserted or removed periodically in order to obtain synchronism between the locomotive unit and the optical link. This does not affect the safety or the reliability, since the control information in the locomotive is evaluated from a number of repeated telegrams.

After the parallel/series conversion the link stores the information, but only one bit at a time. This means that out-of-date information in the form of a whole word will never be stored in the link, which is one of the safety prerequisites.

The optical link is compatible with the electrical link but has a wider field of application. For example, it can be used to

- transmit advanced warning information concerning level crossings (usually at a distance from the crossing that is equal to the braking distance of the train) fig. 13
- transmit advanced warning information to the train when the distance between the signal and the advanced warning signal is large, fig. 14
- transmit information to a beacon situated between two signals in order to increase the capacity of the track. An initiated braking can then be cancelled quicker, fig. 15.

It is also possible to connect several repeater beacons to the same fibre cable and encoder by using optical branching equipment. This provides sophisticated supervision facilities, for example at the approaches to stations.

The fibre cable also permits the use of the alternative laying methods described above.

The optical link has a role to play in future ATC systems because of its insensitivity to interference. The field trials have also proved that the optical link is a reliable and stable part of the ATC system even in extreme environmental and operating conditions.

Further work is now in progress on ergonomic aspects and installation aids, as well as means of improving the installation and maintenance methods, among other things in order to find the best way of fixing the cable to the rail.

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