Pseudo-randomness

Client-specific C-OTDR by Yokogawa and Fibotec solves fiber-optics measuring task in Germany's high-speed

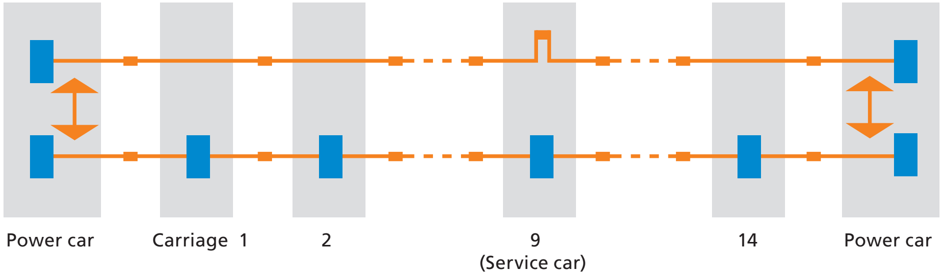
On June 2, 1991, the ICE connection between Hamburg and Munich went into operation via the newly built lines Hanover-Fulda(-Würzburg) and Mannheim-Stuttgart. 1998 saw the completion of the new Hanover-Berlin line, and 2002 the line between Cologne-Rhein/Main. With the addition of the new Nuremberg-Munich line, the Hamburg-Munich connection via Würzburg was improved in 2006. The ICE fleet was expanded accordingly. In 1996, the ICE 2 with pneumatic suspension was introduced. With the ICE 3, in operation since 2002, every second carriage is powered, rendering the need for power cars unnecessary. Between 2005 and 2008, the ICE 1 was redesigned. Further modernization of the propulsion technology is being tested, to – for example – replace the thyristor converter with more powerful IGBT-versions.

State-of-the-art and yet part of history: designed in 1988 in a divided Germany / built while freedom was growing / completed in 1991 in a Germany united – so it says on the commemorative plaque outside the factory entrance. The interior of the hall is decorated with large wall paintings: Hamburg's skyline on the left, Munich's on the right. One would certainly have chosen a different route for the reunited Germany. Nevertheless, the investment in the first high-speed rail line in the country didn't just result in a fast North-South connection but also created one of the most modern trains of its time – the InterCityExpress (ICE). Except for an interim redesign phase, the trains are in daily operation and serviced at least every second day, for example at DB Fernverkehr AG's plant in Hamburg-Eidelstedt.

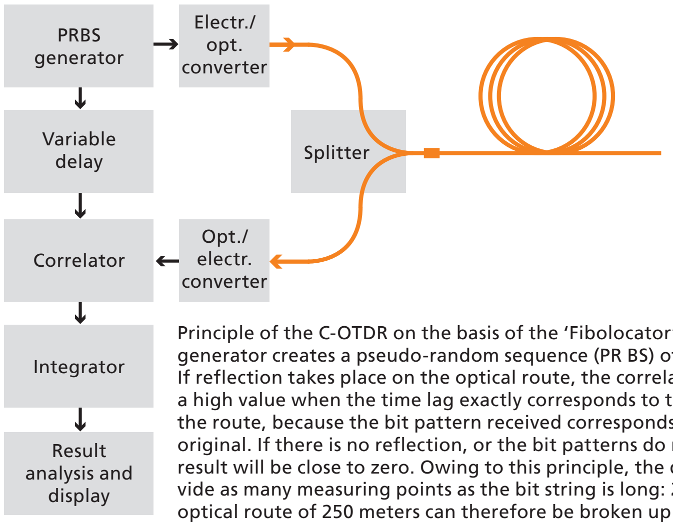
Rail vehicle electrician Hans-Günter Thomas with the C-OTDR in the power car of an ICE 1. The C-OTDR's hardware lies under the laptop console. The software runs on his colleague's laptop. That way, he can save reference curves and observe gradual changes when the train is next serviced at the plant.

Picture right: Access to the power car bus is hidden behind a glass cabinet in the service car. The service car is not the on-board restaurant with its culinary service but the adjacent first class carriage with the train staff compartment.

Among others, the Hamburg-Eidelstedt plant services first generation ICE trains (ICE 1), diesel-powered ICE TD with tilting technology for cross-border traffic to Denmark as well as all other development stages of ICE trains within the plant network of Deutsche Bahn. Routine service does not only include the exterior and interior cleaning and the cleaning of the toilets, but more specifically safety maintenance, including the maintenance of running gear and breaks, repairs – such as underfloor maintenance of the wheelset – or the complete replacement of the bogie. It also means checking the train protection systems, i. e. the train's communication with safety installations along the track such as signals and speed control as well as checking the communication within the train itself.



Fiber-optics cable in the ICE 1. At the top is the power car bus, which is also accessible in the service car. The train bus is at the bottom. The electrical/optical conversion is in blue. Each power car includes possible optical coupling between the buses, switching on automatically in case of a fault.

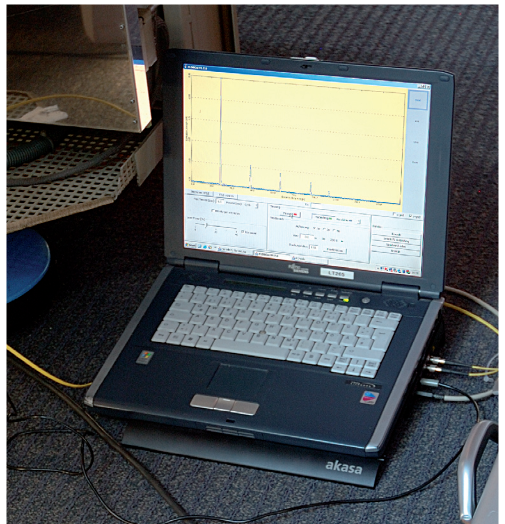


Principle of the C-OTDR on the basis of the 'Fibolocator' by Fibotec. The generator creates a pseudo-random sequence (PR BS) of 256 bits length. If reflection takes place on the optical route, the correlator will display a high value when the time lag exactly corresponds to the duration on the route, because the bit pattern received corresponds to the delayed original. If there is no reflection, or the bit patterns do not match, the result will be close to zero. Owing to this principle, the device will provide as many measuring points as the bit string is long: 256 points. An optical route of 250 meters can therefore be broken up to an accuracy of almost one meter.

Fibotec Fiberoptics GmbH
www.fibotec.com

Example ICE 1: Two fiber-optic cables run through the train. One of them directly links both the power cars in order to control drives and power units and exchange status messages. The second conducts the so-called train bus that transports information to travelers: display of train route, carriage number, seat reservation, next station, estimated time of arrival, exit side; conductor announcements or voice connection with the train driver. The train bus therefore works with one optical/electrical/optical conversion per carriage. As with all safety-critical systems, redundancy is in place. In case the power car bus is disrupted, the power car signals can also run via the train bus and will then have top priority. If, on the other hand, the train bus transmission in a carriage fails, the 'cut-off' carriages can be serviced by running the train bus signals via the power car bus with low priority and then optically feeding them back into the train bus in the rear power car.

Thanks to the optical/electrical conversion in each carriage, the train bus signal is automatically regenerated. By contrast, the power car signal runs the whole length of the train – about 400 meters – without regeneration. Critical points are the optical couplers between carriages. Although these are lens connectors that optically widen the light beam for the air gap and then focus it back onto the fiber, lubricant remnants and other dirt can impair the connection. And finally, the fiber itself inside the carriage can suffer damage after years of use.



Until now, faults have been very awkward to find. "In cases of fiber-optical problems, we had to separate the power train and use trial and error to find the fault. Once halved, then measured, halved again, measured again – if we were unlucky, this resulted in up to five coupling procedures", says Thorsten Reiter about the situation. This was extremely time-consuming because – contrary to loco-hauled trains with single carriages connected through 'hooks and eyes' – the ICE carriages with their pressure-tight car passages are not easily decoupled: the bellows need to be released, the central coupling opened, and according to regulation, the train must only be moved by a train driver.

In earlier development documents, Thorsten Reiter found information about fault localization with a measuring device. Having consulted older colleagues, he was not happy to accept that no solution had been found and contacted Yokogawa. In fact, even Yokogawa with its standard OTDRs (Optical Time Domain Reflectometer) had to pass initially. There are two reasons for this: on the one hand, ICE 1 and ICE 2 use a fiber with the relatively large core diameter of 100 µm, while standard OTDRs use a core diameter of 62.5 and 9 µm, respectively, for the adaptation of multi-mode and single-mode fibers. Even more important is the OTDR principle: the device 'shoots' a short, strong light impulse into the optical fiber and evaluates the reflection, by using the time difference to calculate the points at which the reflections took place.

However, the light impulse itself as well as earlier, strong reflections from the beginning of the line, at first render the detector 'blind'. Consequently, there is a dead band at close range.

In cooperation with Fibotec, a solution was found on the basis of a C-OTDR (Correlation OTDR). In contrast to standard OTDR, a C-OTDR sends a continuous pseudo-random sequence with comparatively low performance. The analysis of the reflections is carried out through correlation of the reflecting signal with the delayed transmission signal. The physical distance can also be directly calculated from the time lag – carried out by the software on a laptop. The advantage: the C-OTDR does not include any dead band.

Thanks to the C-OTDR, one can 'see' up to the fifth or sixth carriage and know what's going on from the very first crossing. It is not a problem that one measurement does not capture the whole length of the train, as the fiber-optic cable can be accessed again in the service car. With a total of four measurements – from both the power cars and in both directions each from the service car – a complete picture of the optical route can be obtained.

"If we now have a fault on the fiber-optic cable, we know immediately: this is where we need to separate. Find the fault, fix the fault – the problem is solved within three to four hours", says Thorsten Reiter. It used to take up to 16 hours – and had implications not just in terms of working hours. "We also have to clear the maintenance hall. Space is expensive, the next train is waiting – I can't block a track for two whole shifts." Economically, Thorsten Reiter doesn't need long to calculate: „Even taking the cost of the measuring device into account – with a three-fold improvement of the process, the device is paid for."

Thorsten Reiter (left) with Jörg Latzel, Yokogawa's optical specialist. Six years ago, Thorsten Reiter started working at DB Fernverkehr AG in Hamburg-Eidelstedt as a production engineer in traction engineering and is now also looking after train systems.

Official website for Deutsche Bahn AG:
www.deutschebahn.com

Quelle: Yokogawa Test- und Messtechnik Hausmagazin, Ausgabe 18/2010 „Titelgeschichte der DB Fernverkehr AG" (Deutsche Fassung übersetzt ins Englische)

Yokogawa Deutschland GmbH
Niederlassung Herrsching,
D-82211 Herrsching