

Safe Lane Guidance System

By Hans Happ, FAE EBV Elektronik Kaarst

We are all familiar with the basic principle of the application described in this article since it involves a system for guiding vehicles safely from one lane to another by means of luminous (in Germany, yellow) lane markings, a task that, at first sight, might seem rather trivial, even very simple. On closer examination, however, it turns out that such a system is in fact highly complex, not least because of the extremely stringent safety requirements. Guiding traffic by means of luminous markings sunk into the road surface is highly challenging both with regard to the electronics and mechanics involved. Using LED technology and LonWorks powerline communication as a basis, the Lübeck-based company that has collaborated with EBV-Elektronik to create a perfect solution delivering optimal performance with regard to both the electronics and mechanics.

When you drive across the six-lane Golden Gate Bridge from the north towards San Francisco during the morning rush-hour, concrete blocks 50 cm high and 80 cm long guide you along four lanes heading south, while the other two lanes head north out of the city. Just before the evening rush-hour strikes, however, the concrete blocks have to be repositioned to ensure optimum utilisation of the six lanes. During the peak evening period, four lanes are available for traffic heading north out of San Francisco, while just two lanes are available for traffic heading towards San Francisco.

Pioneering project featuring an electro-optical traffic guidance system: the Elbe tunnel

When the fourth of the 3.2 km, two-lane tunnels was planned and built 32 m below the surface and a good 12 m below the bed of the Elbe, the operators wanted to install a more elegant lane guidance solution than the ones currently in place, not only in the Elbe tunnel but also in the rest of the world. Yellow luminous markings – ‘surface lights’ – were to replace the mechanical guidance system (concrete blocks or beacons) for directing traffic into the correct lanes. The aim was to avoid the laborious task of mechanically repositioning the blocks or beacons and the associated lane closures, which are both costly and time-consuming. The solution was finally taken into operation in 2004. It features 656 electronically controlled surface lights that lead up to the Elbe tunnel and are arranged in 39 separate light chains with cable lengths of up to 600 m (whereby some chains only supply four surface lights and others up to 42 surface lights). The surface lights are sunk into the road surface at five-metre intervals and connected by cables with lengths ranging from 100 m to 150 m.

The surface lights are operated by a control system that has functioned reliably and in a practically-unchanged form since the solution was taken into operation and uses powerline communication based on Echelon technology.

Surface lights: a mechanical challenge

The basic mechanical elements of this solution are highly robust surface lights (Fig. 3), like the ones followed by aircraft taxiing to or from terminals. Although the surface lights installed in airports are designed to withstand, time and time again, the weight of a fully laden Airbus A380, it quickly became apparent that the mechanical stressing on motorways is considerably higher.

The *who* **Ingenieurgesellschaft** which, in its capacity as development partner in the LonWorks sector for Siemens Traffic Solutions, was responsible for developing not only the surface lights but also the systems allowing them to communicate with master computers. It also quickly established that the majority of design challenges actually concerned the mechanics: “Despite our many years of experience in developing systems designed for harsh maritime conditions, the mechanics, optics and sealing of the surface lights and IP68 connectors was

new territory for us”, explains qualified engineer Detlef Thon, managing partner of *who Ingenieurgesellschaft* mbH, which is headquartered in Lübeck. “The powerline communication and lighting control systems may not have been easy to develop, but they were as nothing compared with the numerous mechanical challenges. Before the system was installed, we performed type-testing on five surface lights on a vibration test bed with 10 g at an amplitude of 1.2 mm in the range 20 Hz to 100 Hz in accordance with EN60068-2-6. In the final test, the individual parts were submerged under water at a pressure of 1.4 bar and tested to ensure that they are leak proof. Only high-end technology can withstand these conditions.” Although discussion about the extreme mechanical stressing imposed by up to 150,000 vehicles a day, both cars and trucks, would certainly be of interest to electronics technicians, this article focuses instead on the electronic elements of the system.

LED control

When *who* engineers began development on the surface lighting system, the initial plan was to use halogen lamps. As Detlef Thon explains, however, “we quickly realised that halogen lamps were not viable here and that LEDs were a much better solution. Not only do LEDs use 75% less energy than halogen lamps, but halogen lamps would need to be replaced every 1,000 to 1,500 hours on a preventive basis, which would involve immense time and effort when you consider the lane closures and so on this would entail. At the start of 2009, some lights had been permanently illuminated for almost 19,000 hours and in service for over 20,000 hours without any trouble.”

The core optical elements of this basic design, which is now five years old, are six Osram Dragon LEDs with an output of 1 W. Although *who* implemented early prototypes featuring LEDs from a different manufacturer, it was found that the relatively large metal surface on which the chip was mounted caused dangerous and distracting phantom lights, which meant that, despite their brilliance, these LEDs were not suitable for this application. Phantom lights occur when light is reflected in such a way that the light source appears to be activated, a phenomenon we are all too familiar with from traffic lights fitted with light bulbs. “While standard applications only yield 100 candela, Dragon LEDs, in conjunction with a specially developed optical system, yield a luminous intensity of 1,200 candela”, explains Detlef Thon. “This means that we fulfil police requirements that drivers can easily see the markings from a distance of 85 metres, even when the sun is low in the sky”.

Since the surface lights are designed to be clearly visible both during the day and at night, as well as at different solar altitudes and cloud conditions in summer and winter, the brightness must be controllable. *who* has achieved a dynamic range from the minimum brightness to the maximum that encompasses an impressive 14 bits – a value that pulse-width modulation alone could not achieve without additional circuitry.

To achieve consistently reproducible brightness values, the system monitors not only the forward voltage of the individual LEDs and the current flowing through them, but also the temperature of the LEDs as well as the driver and control electronics. Since the effectiveness of the LEDs increases as the temperature decreases, a special control system ensures that a lower current flows through the LEDs in winter than in summer – a feature that is implemented only very rarely.

In this application, safety is paramount. To ensure that the failure of a surface light does not go unnoticed, each individual light permanently supplies data on 39 different measured values and operating conditions. These values, which are supplied from almost 40,000 separate data points, are collected in a central database that stores the data for 60 months in a circular buffer, thereby enabling operators to analyse data from the past five years.

Powerline communication

These operating and measured values are transferred continuously to the data centres via a power supply cable by means of powerline communication. The 656 surface lights are arranged in 39 individual chains (Fig. 4) which, in turn, can be assigned to different operating conditions, whereby the central controller assigns the same operating conditions to all the surface lights in a particular chain. The monitoring and control data is transferred by means of powerline communication. To enable this, the surface lights are permanently connected to the 230 V network and are each equipped with their own mains power supply and local control module electronics. This control module is equipped with the 'Power Line Smart Transceiver PL3120' from Echelon as well as the electronics required for controlling the LEDs and monitoring the entire unit.

who **Ingenieurgesellschaft** has specialised as a service provider for Echelon/LonWorks and, even prior to the Elbe tunnel project, had extensive experience in the area of building and system automation. It was this knowledge that the company, while also leveraging the experience and know-how of the Echelon distributor EBV-Elektronik, was able to bring to bear when planning this powerline system. As early as 1996 and 1997, *who* convinced the planning team that powerline technology was, despite – or even because of – the adverse secondary conditions, the ideal solution for this safety-critical application.

The powerline system means that, among other things, switching cabinets containing dimmers and controllers are no longer required on the roadsides, which is one less traffic hazard to deal with. Since all the monitoring equipment is housed locally within the surface lights themselves, the 'only' thing that was still needed was a highly reliable connection to the command centre. Although permanent monitoring takes place in the background and the relevant data is transferred via the powerline connection, the bandwidth of this powerline connection (5.4 Kbit/s) in the chains for the application is large enough to cope with the lively communication activity that takes place between the surface light and the traffic master computer when the chains are switched from one operating status to another.

The detailed plans prove that implementing LonWorks powerline communication was the right decision. To the south, the road leads onto a bridge as it exits the tunnel. If each surface light were wired individually from a switching cabinet, the structure of the entire bridge would be severely perforated by all the cables. Thanks to powerline technology, however, all the cables are housed in armoured conduits with a diameter of just 6 cm, a solution that does not pose any structural problems.

'Problems' in practice

The individual power cables run immediately parallel to each other over a distance of up to 400 m. Although they are shielded 230 V cables, crosstalk can occur between the surface light chains. "Powerline communication technology from Echelon is simply too good", says Detlef Thon. "Echelon has essentially channelled all its efforts into maximising range, something that requires a high degree of sensitivity. Echelon has certainly achieved this, but this high degree of sensitivity caused us some difficulties as we had to separate the individual chains with regard to communication."

To achieve this, *who* developed special band elimination filters that separate the powerline communication frequencies from the joint 230 V power supply. Each chain is equipped with its own filter. Since there is a 3.5 km long fibre-optic connection between the north and south entrances of the tunnel, the powerline systems on the north and south sides are not connected in electrical, inductive or capacitive terms, which means that a filter can be installed on both the north and south sides.

System level

The communication chains that connect the surface lights each terminate in one of the seven roadside stations (four in the north, three in the south). These roadside stations are like large switching cabinets: small, walk-in cabins situated next to the motorway, equipped with heating and air-conditioning as well as a range of monitoring systems, such as cameras and height monitors. In each roadside station, an Internet server of type i.LON100 connects the LonWorks environment (powerline communication to the chains each with 5.4 Kbit/s) to Ethernet-based (10BaseT) IP data networks, whereby i.LON100 functions as a TCP/IP/FT router. Communication between the roadside stations and the control room takes place via optical fibres.

To meet safety requirements, the top administration level features two main systems: the central traffic master computer (which also assumes executive control) and the visualisation system for the local control module. The central traffic master computer is responsible for functional, traffic-related control (e.g. guiding traffic from the two right-hand lanes into tunnel 3) and receives status reports from each individual surface light. The visualisation system for the control module, however, is used purely for visualisation, data storage, and administration (logical replacement of a light) as well as for initiating chain tests. In this way, service technicians can tell simply by looking at the visualisation system, which surface light has failed or is causing problems.

If two consecutive surface lights fail, however, a gap appears in an otherwise unbroken line which, according to traffic law, a vehicle could theoretically drive through. For this reason, the traffic master computer has to identify these kinds of situations in good time, assess them, and then decide whether or not, for example, an emergency stop needs to be triggered.

The chains themselves can only be controlled via the central traffic master computer, a process that takes place exclusively via distributed I/Os in the roadside stations. These are processed by means of a WAGO I/O system (field bus controller) and communicate with the separate chains via the LonWorks powerline router by means of FTT (Free Topology Transceiver) and LonWorks. An exclusively software-based control system was not deemed safe enough by the members of the safety committees, which is why they decided instead to opt for this rather unusual approach featuring a discrete hardware interlock level.

EBV-Elektronik supplied the Echelon/LonWorks products to *who* **Ingenieurgesellschaft**, which then integrated them in the system. “In this system, we have implemented the LonWorks technology via powerline, FT and Ethernet media as an open standard”, explains Detlef Thon. “The systems work both with and alongside each other very well. We also developed the powerline router ourselves, which is based on the core router module from Echelon.”

((kleiner Kasten))

who Ingenieurgesellschaft

... is among the world's leading service providers and developers in the LonWorks technology field. For example, Detlef Thon, who is one of the managing partners, has been working in the LonWorks field since 1993. In those days, however, and working with a 68000 processor, he had to convert LON (TP/XF-78) to Ethernet all by himself. In response to the increasing popularity of LonWorks in a wide range of applications, *who* has expanded its specialist competencies in different areas and now acts as an outsourcing partner for product developments requiring extensive, multi-sector expertise. Most projects involve communication solutions based on all the common standards, such as LonWorks, Ethernet or DALI. *who* enjoys excellent relations with the Echelon distributor EBV-Elektronik, and not just in the LonWorks field.

The range of activities covered by *who* encompasses consulting, compiling performance specifications for hardware and software development, interfacing and/or embedding hardware and software in other systems, certification and production support.

In the Elbe tunnel project covered here, the range of activities performed by *who* involved developing the electronics for the local control module LED surface lights and powerline routers, the band elimination filters, the test bed assemblies for series manufacture, as well as a range of software (e.g. the embedded application in the DSR module, the embedded application in the field bus controller, the IEC61131 application in the field bus controller, and 11 PC LNS applications for the various devices), commissioning, replacement, production etc., as well as developing the entire visualisation system for the local control module based on Citect HMI/SCADA software with around 40,000 data points.

((Bildunterschriften))

Fig. 1: The yellow surface lights replace the red-and-white marker beacons.

Fig. 2: The surface lights have to function properly even under extreme conditions and in water.

Fig. 3: The principle of lane guidance by means of surface lights

Fig. 4: The separate local control modules (surface lights) communicate within the system via LonWorks powerline connections.

Fig. 5: Schematic representation of the control system for the surface lights in the Elbe tunnel (Hamburg, Germany)

All images and diagrams: *who* Ingenieurgesellschaft/Siemens