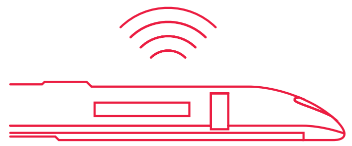
Image: DLR/Henrik Frensch

HIGH-SPEED CHASE FOR SIGNALS



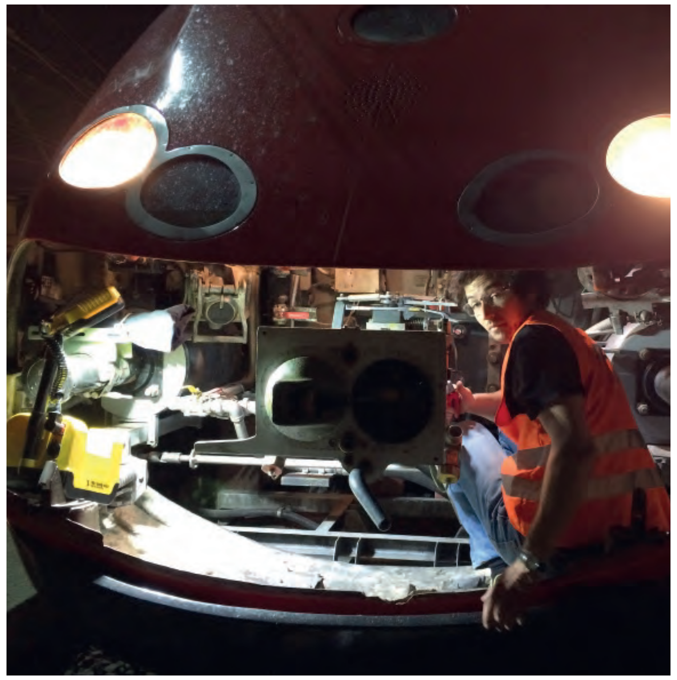
Report from a nocturnal measurement campaign in the Italian express train Frecciarossa

By Julia Heil

It is 23:00, and the train depot in Naples is bathed in yellow light. A deafening hissing sound fills the air as a train pulls into the depot and slowly comes to a halt. Two tracks ahead, a spotlight in the ballast of the track bed illuminates the open front of a railcar. It is an unusual sight: Paul Unterhuber, a researcher from the DLR Institute of Communications and Navigation, is sitting in the train's nose, mounting a measurement antenna and a distance radar. Highly concentrated, he connects the individual units: the red cable with the blue, the green with the brown – a meticulous job where caution is advised. Excessive bending of the cables could lead to problems during the measurement campaign that Unterhuber is leading. The rest of the train is a hive of activity: laptops are set up, cables are passed to and fro and the ceiling panels are removed to connect additional antennas. "I need some help here at the front again! We have to hurry a bit if we want to meet train 28 at the station on time," calls Unterhuber to the front car.

Image: RDLR/Henrik Frensch

The two Frecciarossa high-speed trains are 328 metres long and can travel at speeds of up to 360 kilometres per hour. In their noses, the scientists installed measurement antennas and a proximity radar to accurately determine the distance between the two trains and exchange information between them.



The work in the train nose demands dexterity and physical exertion from Paul Unterhuber.

Like number 7, in whose nose the antenna for the radio channel characterisation has just been mounted, number 28 is also an Italian high-speed train – a Frecciarossa (Red Arrow). Tonight, these two trains are neither occupied by passengers nor waiting to be cleaned in the depot, which would be more usual at this time of day – they are occupied by an 11-person team from the DLR Institute of Communications and Navigation. The scientists are using the two high-speed trains to study train-to-train communication during their journey. The high-speed line between Rome and Naples provides the team with 206 kilometres of track to conduct investigations during nocturnal test runs. The researchers want to find out how the exchange of information between two trains travelling at full speed can be made reliable enough for train control purposes. In preparation for the measurements, Unterhuber travelled to Naples and Vicenza beforehand and equipped the measurement trains: four antennas on the roof of train number 28, two antennas on train number 7 and no less than 150 metres of measuring cable straight through carriages and locomotives. Five more antennas have to be installed tonight.

Unterhuber is now working in the open train nose and is making a telephone call. At the other end is Stephan Sand, Leader of the Vehicular Applications Research Group at the Institute of Communications and Navigation and team leader of the research campaign. While Unterhuber has taken care of the last installations in train 7, Sand has been making sure that train 28 is ready as quickly as possible. “We are ready. See you in the station soon,” says Unterhuber into the phone. And minutes later, the train slowly begins to move.

Signal interference after midnight

With 50 million travellers per year, Naples Central Station is one of the most important railway stations in Italy. When the two trains arrive at around 01:00, the station is almost at a standstill – a few passengers are still travelling and a crew is dutifully cleaning the platforms. The scientists are in a hurry, as every minute in the station is one minute less of measurement time. And at the starting signal everyone must be sitting in the right train. Equipment is exchanged between trains – with a length of 328 metres each, this is a time-consuming affair. The transmitting and receiving units are being calibrated inside the passenger cars. Everyone sits concentrated by their instruments. Michael Walter, Wei Wang and Thomas Jost lean over a large box, the so-called Channel Sounder. Walter is suddenly concerned: “I hear a clicking noise – not a good sign!”

Using the Channel Sounder, the scientists want to accurately characterise the transmission channel between the two trains. A pulse with a bandwidth of 120 MHz is emitted by the transmitter unit at 5.2 GHz and reaches the receiver unit, which is located on the other train. Based on the signals, the scientists can make predictions about how a particular environment affects the transmission signal. A model for the radio channel is created using the results of the measurements. Based on this, communications systems with which trains can exchange information while moving will be developed in the future. Tunnels, bridges, forests – they should all be identifiable in the received signal. Yesterday, when the team carried out measurements in a single train, everything worked flawlessly. Today, however, there are problems with the calibration – the scientists are receiving signals that do not fit into the scheme.

Several colleagues have now gathered around the measuring equipment and are trying out various solutions – still, the scientists are receiving signals that they cannot explain. Meanwhile, the two trains are somewhere between Naples and Rome, and time is running out.

Finally, Unterhuber draws the line: “If we don’t succeed by three o’clock, then we will only measure with the other instruments. We have to get going and should not lose any more time.”

At 03:00, with persistent calibration issues, the train starts moving.

Michael Walter, Wei Wang and Thomas Jost begin packing up the equipment. Disappointment is spreading. Tonight has, at least for the measurements with the Channel Sounder, been a lost cause. But the tight schedule no longer allows further troubleshooting. Tomorrow, the scientists will spend several hours meticulously checking every connection and every cable to find the fault. The overhead line most likely caused the disturbances in the signal. Over the next two nights, the team will achieve good measurement results with the Channel Sounder and will be able to precisely characterise the radio channel between the two moving high-speed trains. Tonight, however, everybody is none the wiser. Therefore, the three scientists cannot but take a short break after everything has been stowed away – the night is still not over. Now, Paul Unterhuber finally has a little time to eat a slice of his pizza, which sadly went cold a long time ago.

Collision avoidance at high speed

A different picture presents itself when you look back: In the driver’s cab at the back of the train, Thomas Strang’s gaze is directed towards a small laptop monitor, with a telephone in one hand and a radio within reach. “220 kilometres per hour – maintain speed,” he speaks into the handset. He is talking to the driver at the front while maintaining contact with his colleague Andreas Lehner in the train that is following them. Strang looks out the window – the lights at the edge of the track seem to fly past. There is no sign of train number 28. But it is not far away. Strang points to his laptop, which displays the data from the Railway Collision Avoidance System (RCAS): “I can see the other train here. At the moment, we are about 10 kilometres apart. But it is steadily catching up and we should be able to see it soon.” Indeed, a short time later, lights appear from around a curve announcing the approach of the moving train.

The RCAS system installed in the two high-speed measurement trains is continuously recording relevant parameters such as position, route, speed and braking power. This information is transmitted to all trains in the vicinity. While travelling, the system compares its own parameters with those of the other trains. The exact knowledge and comparison of parameters make it possible to quickly identify potential conflict situations. Another advantage of the system is with regard to line occupancy – currently, the track sections between two trains are always calculated using the maximum braking distance required. If there is a train in a particular section of the track, the train that follows must keep a distance of up to 10 kilometres. With the RCAS system, tracks could be used more efficiently in future because the braking distance can be accurately determined at any time.

In a brightly lit tunnel, the two ‘red arrows’ have finally drawn level at a speed of approximately 250 kilometres per hour. When passing, Sand, who controls the measurements in train number 28, can be seen through the windows of the front carriage. Strang directs the overtaking manoeuvre: “Increase speed, yes, that is good. The others are travelling at 230 kilometres per hour, so we will keep our speed at 250 and move steadily past them.” His system is working flawlessly – even at high speed. His face glows with pride: “We are doing RCAS at 250

THE PROJECT

For four nights, the DLR researchers investigated wireless train-to-train communication in and between two high-speed trains in Italy. The Italian partner Trenitalia made two Frecciarossa high-speed trains available to them. The measurements were carried out as part of the EU Roll2Rail project on the high-speed line between Rome and Naples. The measurements in Italy were carried out as part of the European Union (EU) Roll2Rail project. Roll2Rail is one of the lighthouse projects of Shift2Rail within the Horizon 2020 programme. Thirty-one European partners are working on the development of key technologies, increasing reliability in the railway sector and reducing costs. The Roll2Rail project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 636032. The project is closely connected to the DLR Next Generation Train project.

Image: DLR/Henrik Frensch

The Channel Sounder consists of a transmitter and a receiver unit. The receiver reveals how the radio signal is reflected by the environment.

kilometres per hour – this has never been done!" On the last night of measurements, the team will even exceed this record on an intersecting trip at a relative 560 kilometres per hour – and then, too, the system will work to perfection.

Radio link saves changing trains

In addition to the RCAS system, with the ITS-G5 (Intelligent Transportation System at 5 GHz), the DLR scientists have yet another system on board for exchanging information between trains. It is designed for the high-rate exchange of information, and was originally developed for road vehicles. It works like the RCAS system, without having to rely on cell towers or other components along the way – but so far only over short distances. While the RCAS system can still receive a signal at a distance of up to nearly 40 kilometres, the ITS-G5 tends to lose the connection after approximately 1.2 kilometres.

With the measurements from the ITS-G5, the researchers want to lay the foundations for the so-called dynamic coupling of high-speed trains. In this manoeuvre, which is also called virtual coupling, the trains will automatically connect while moving to form a longer train and can also separate into individual trains again. The trains travel one after the other, only connected over a wireless communication link. The closer the railway vehicles are, the more precisely they must exchange information about their position and speed. This is the only way to adapt to each other and behave as a single, long train. The advantage of this is that passengers can reach their destinations without changing trains. Time-consuming coupling and uncoupling manoeuvres in stations are also avoided. In addition, the capacity limits of the routes can be increased with the dynamic coupling.

Train 28 overtakes train 7 several more times and drops back again immediately. Dawn is breaking, but most of the nocturnal researchers are unaware. Their only focus is their measurement instruments. When the two Frecciarossas make it back to the depot in Naples, the Sun is rising. The instruments are carried out of the carriages and the cleaning crew boards the trains and gets to work.

After their night as a communication laboratory, it is time for the two Red Arrows to do what they always do: transport passengers. For the scientists, however, it is now time to go back to the hotel and sleep…

Just before the start of the campaign, Stephan Sand from DLR and Maurizio d'Atri from Trenitalia complete the last formalities.

Care must be taken when the sensitive Channel Sounder is pushed into the train carriage.

THE CHANNEL SOUNDER: 15 YEARS OF SIGNAL ANALYSIS

In the development of new communication systems, it is important to know and capture the radio channel between the transmitter and receiver as accurately as possible. The better a channel can be understood and defined, the more accurately the transmitter and receiver can be attuned to the environment. The so-called Channel Sounder is used to characterise the radio channels.

A signal that is broadcast from a transmitter undergoes reflections from the environment before it reaches the receiver. In the vicinity of a train travelling at high speed through a tunnel, the signal is reflected differently than that of a satellite radio link to a receiver in a wooded area. Such reflections and other effects such as diffraction cause signal distortions. Since the transmission signal from the Channel Sounder is known, the scientists can accurately measure the signal distortions that the transmitted signal experiences on its way through the radio channel.

The nature of the ground that reflects the signals from navigation satellites also plays a role in the behaviour of the signal. From 2014 to 2015, various measurements were carried out by a team of scientists, which mounted the Channel Sounder transmitter and receiver on two 40-metre high cranes. The properties of the asphalt of a runway, of water and of an ice-covered lake were measured.

All the same, whether it comes to future communication systems or whether new applications are being designed, without the Channel Sounder, communication would be a shot in the dark. With today's navigation systems, such as Galileo and GPS (Global Positioning System), it is currently not possible to make precision positioning inside buildings. The measurements with the Channel Sounder should change this. In 2008, the scientists succeeded in characterising the transmission channel of a simulated navigation satellite to an improvised pedestrian inside a building using the Sounder.

In addition to measurements for systems such as Galileo and GPS, the Channel Sounder is also used for the preparation of new communication systems. Scientists have investigated the communication channels from aircraft to aircraft (2009), from car to car (2013), and from ship to ship. While in 2014 measurements were carried out in the Baltic Sea in calm sea conditions, in 2016 DLR scientists investigated the reflections from the waves and the water around the island of Heligoland in the North Sea in gale force seven winds.

For 15 years, the Channel Sounder has been a proven measurement instrument for researchers at the DLR Institute of Communications and Navigation. In the Roll2Rail measurement programme in Italy in 2016 it proved its worth once again: scientists gathered valuable information about the characteristics of the radio channel in train-to-train communication.

In 2002, DLR researchers investigated the radio channel between a measurement bus and a Zeppelin using the Channel Sounder.

To measure the ground reflections of a radio signal emitted from an aircraft or a satellite, the scientists installed the Channel Sounder on a 40-metre-high crane during tests in 2014 and 2015.