

High speed real-time contact
measurements between a smart train
pantograph with embedded **Fibre
Bragg Grating** sensors and its
Overhead Contact Line



EU FP5 RTD project **SMITS** (**S**mart **M**onitoring **I**n **T**rain **S**ystems)

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This should belong to the past



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SMITS project overview

Innovative Embedded Sensors for
Monitoring purposes

Problem addressed

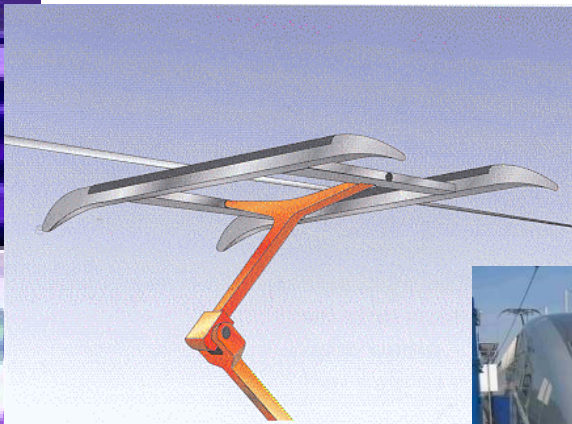
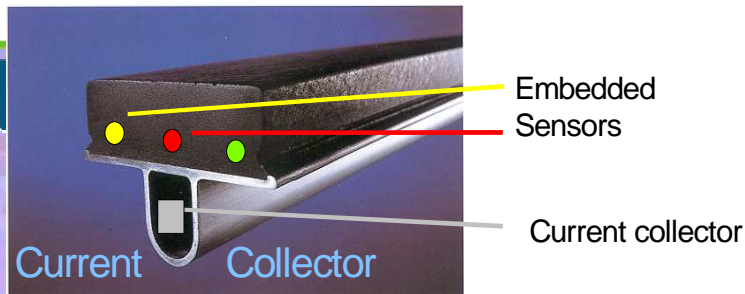
New needs for diagnostics on trains and electrical infrastructure due to the deregulation and interoperability of EU track.

Expected impacts

- _ Enhanced **cost transparency** for operators
- _ **Predictive maintenance** possible
- _ **More efficient, faster** and **safer** use of existing rolling stock
- _ Increased **interoperability**

Project summary

Permanently **monitoring the thermal & mechanical stress load caused by a train** running under the OCL allows the resulting wear to be predicted.



Key figures

60 000 km EU railway network
4 to 5 pantograph failures/(100 km.year)

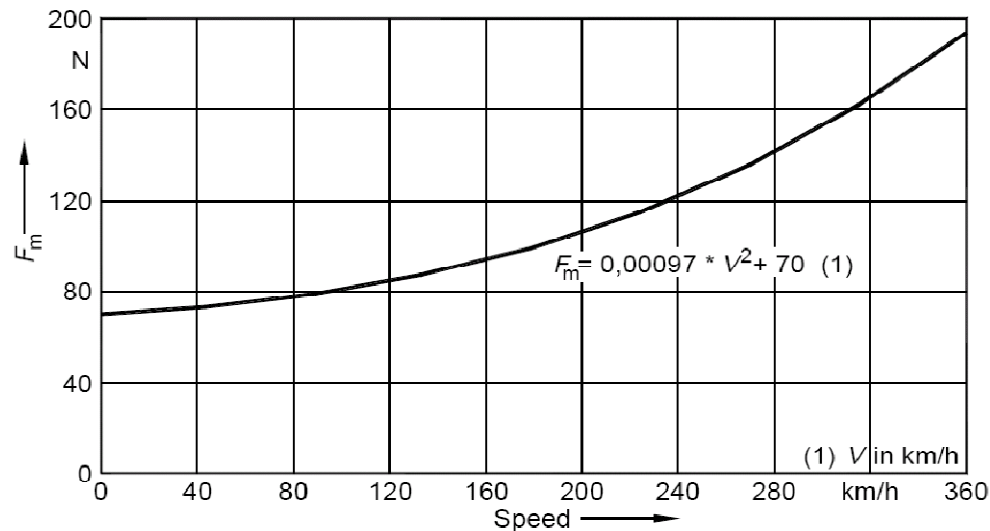


Siemens AG [D] – Morganite Electric Carbon [U.K.]
SNCF [F] – IPHT [D] – CEA LIST [F] – BLS [CH]



SMITS project objectives

- **To develop a EM immune sensor sensitive to vertical force [F] and temperature [T] in order to have:**
 - **20 cm** resolution for OCL flaws (up to 320 km/h)
 - **1 cm** precision for OCL position on the current collector
 - **1 N** precision for vertical contact force

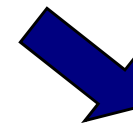
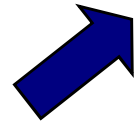


Target for mean contact force F_m for AC systems depending on running speed [from TSI standards]

- **Force, position and temperature measurements to be available in real-time**
 - CEA LIST to deliver a monitoring system for TGV very high speed on-line tests

Optical Fibre Bragg Gratings (FBG)

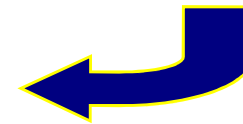
Local refractive fiber core index perturbation



Photosensitivity of Germanium doped silica fibers

Spectral filter used as **transducer**

$$\lambda_B = 2.n.\Lambda$$



$$\frac{\Delta\lambda_B}{\lambda_B} = a \frac{\Delta T}{T} + b \Delta\varepsilon + c \frac{\Delta P}{P}$$



with $\begin{cases} a \approx 2.3 \times 10^{-3} \\ b \approx 0.78 \\ c \approx -2.94 \times 10^{-6} \end{cases}$

temperature, strains, hydrostatic pressure ...
excellent metrological performances in terms of
linearity, resolution, range ...

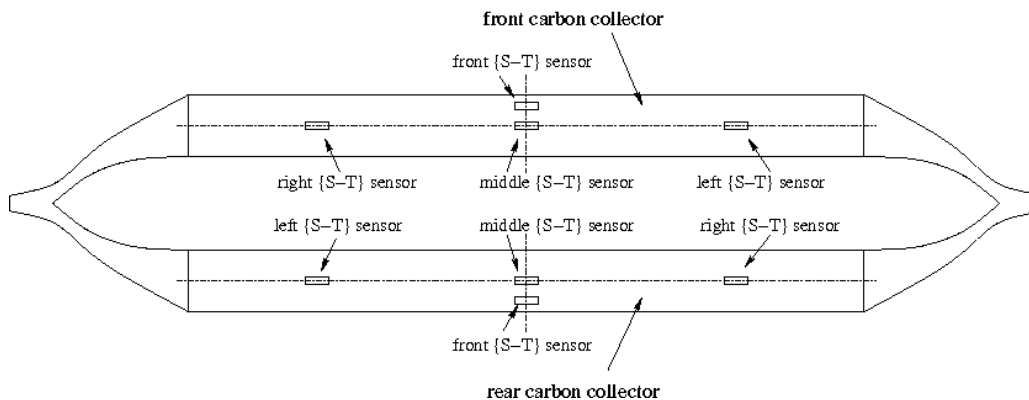
FBG the right solution?

FBG advantages

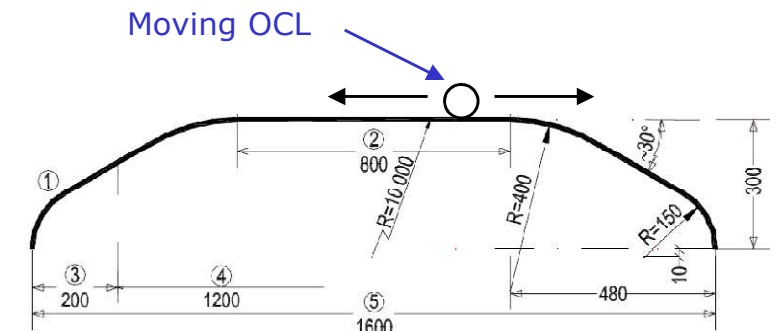
- In-situ and low intrusive measurements
 - OD: 155 μm
- EM immunity
 - Enables measurements at 25 kV without specific insulation
- Linearity over a wide range
 - Up to 5% (1% in practice)
 - Up to 300°C for traditional FBG
- Resolution and precision
 - Depend mainly on the measurement system
 - 2007 state of the art: better than 1 pm @ 1550 nm
 - Equivalent to $\Delta T = 1/12$ °C and $\Delta \epsilon = 0.8$ $\mu\text{m}/\text{m}$
- Wavelength multiplexing capabilities
 - Several sensors located on the same fibre

FBG sensorised pantograph

- **Sensors to be located as close as possible to the contact point: into the current collector**
 - To be less sensitive to inertial forces
 - Not to take into account mechanical behaviour of other pantograph suspending devices
- **A current collector turned into a sensor**



CX25 TGV pantohead equipped with FBG sensors



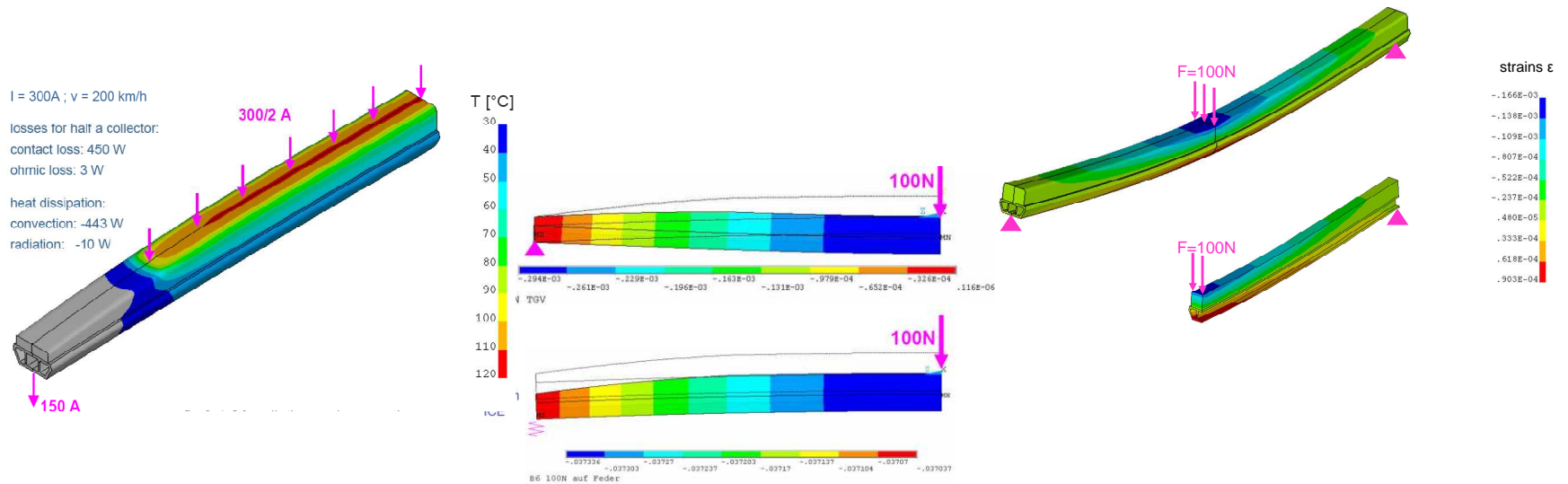
Profile of current collector head [TSI standards]

- 2 middle + 1 right + 1 left = 4 $\{\epsilon, T\}$ sensors per collector
 - Underlying 3 points bending model for vertical force and contact position measurements

Monitoring system impact



- **Resolution and precision to be better than 1 pm @ 1550 nm**



FEM thermal and mechanical modelling of the current collector [from Siemens]

- **Measurement rate $\geq 500 \text{ Hz}$**
- **Absolute [\neq relative] force, temperature and position**
 - Wavelength measurements to be accurate, without any drift vs. time



CEA LIST monitoring system design



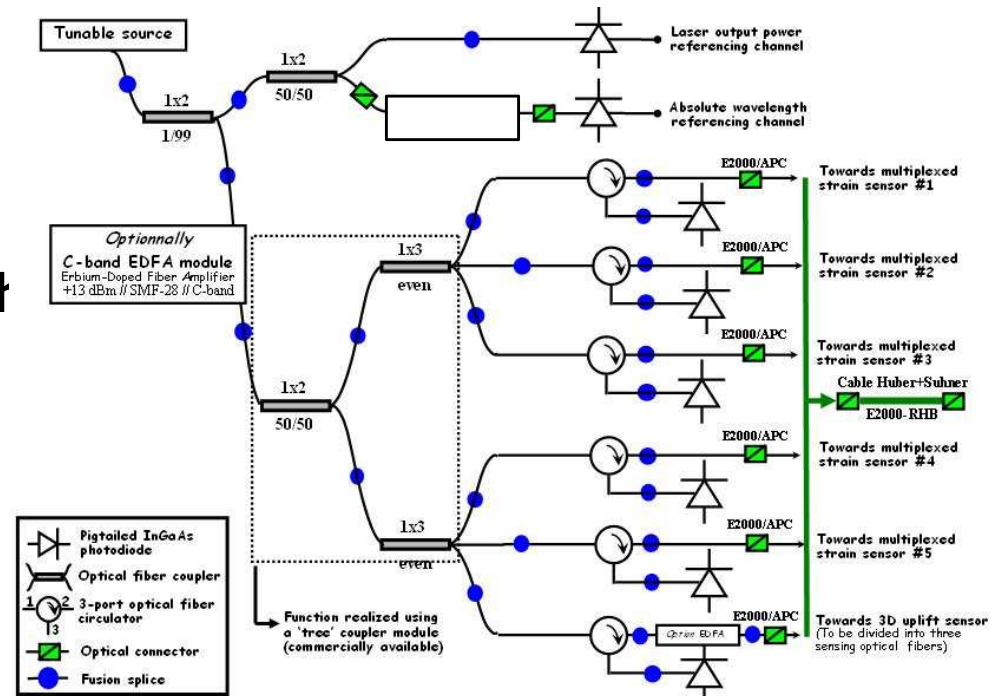
- **FBG specific topology**

- 2 current collectors per pantograph (Faiveley CX25 model)
- 4 sensors per current collector – 2 FBG per sensor

→ 16 FBG spread on **4 optical lines**

- **Core system: dedicated high speed tunable laser source**

- High emission power
 - 4 mW
 - 0.5 pm emission peak width
- Fast tuning rate (500 Hz)

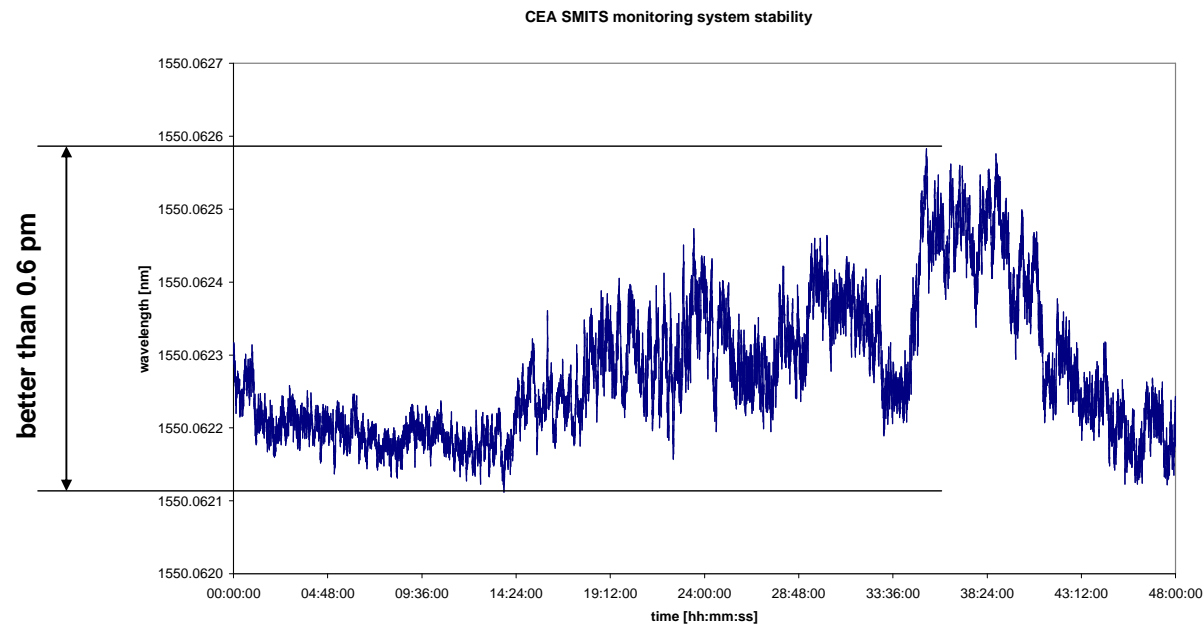


CEA LIST monitoring system architecture [from Catiemon project]



Monitoring system performances

- Ability to scan 4 optical lines in parallel at 500 Hz
- Absolute Bragg wavelengths measurements thanks to internal wavelength references
- Drift ≤ 0.6 pm
- Dynamic range ≥ 40 dB
- Accuracy and precision better than 1 pm @ 500 Hz



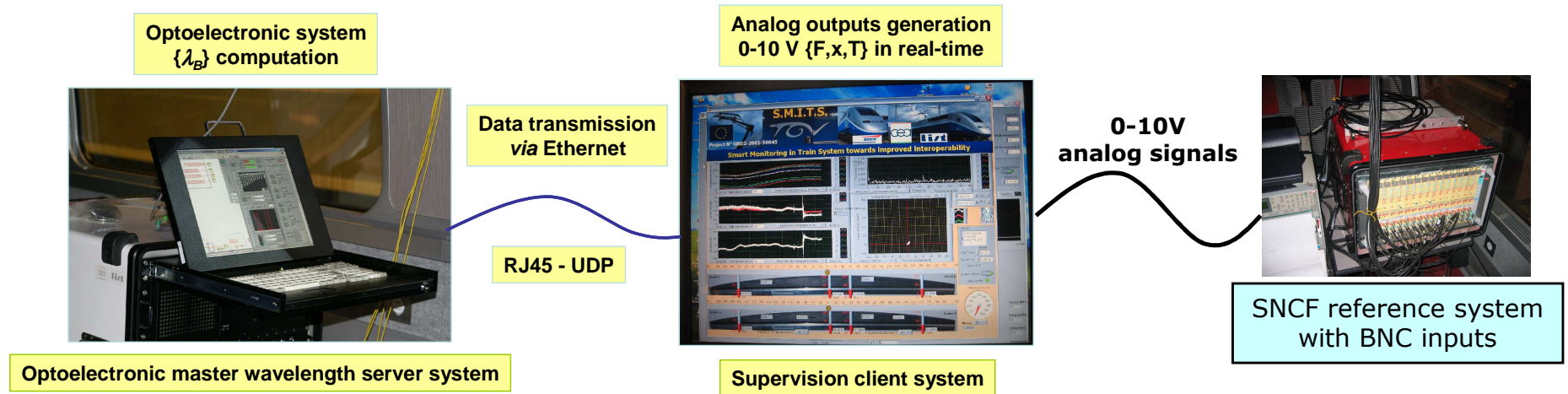
CEA LIST monitoring system stability 2 days test



Monitoring system integration



- **Integration into a standard 19" industrial rack**
- **Client-server architecture philosophy**
 - 1 master system manages the optoelectronics, computes in real-time the Bragg wavelengths and broadcasts them on a private TCP/IP LAN
 - Local clients use the broadcasted data for their specific needs (F, x, T)



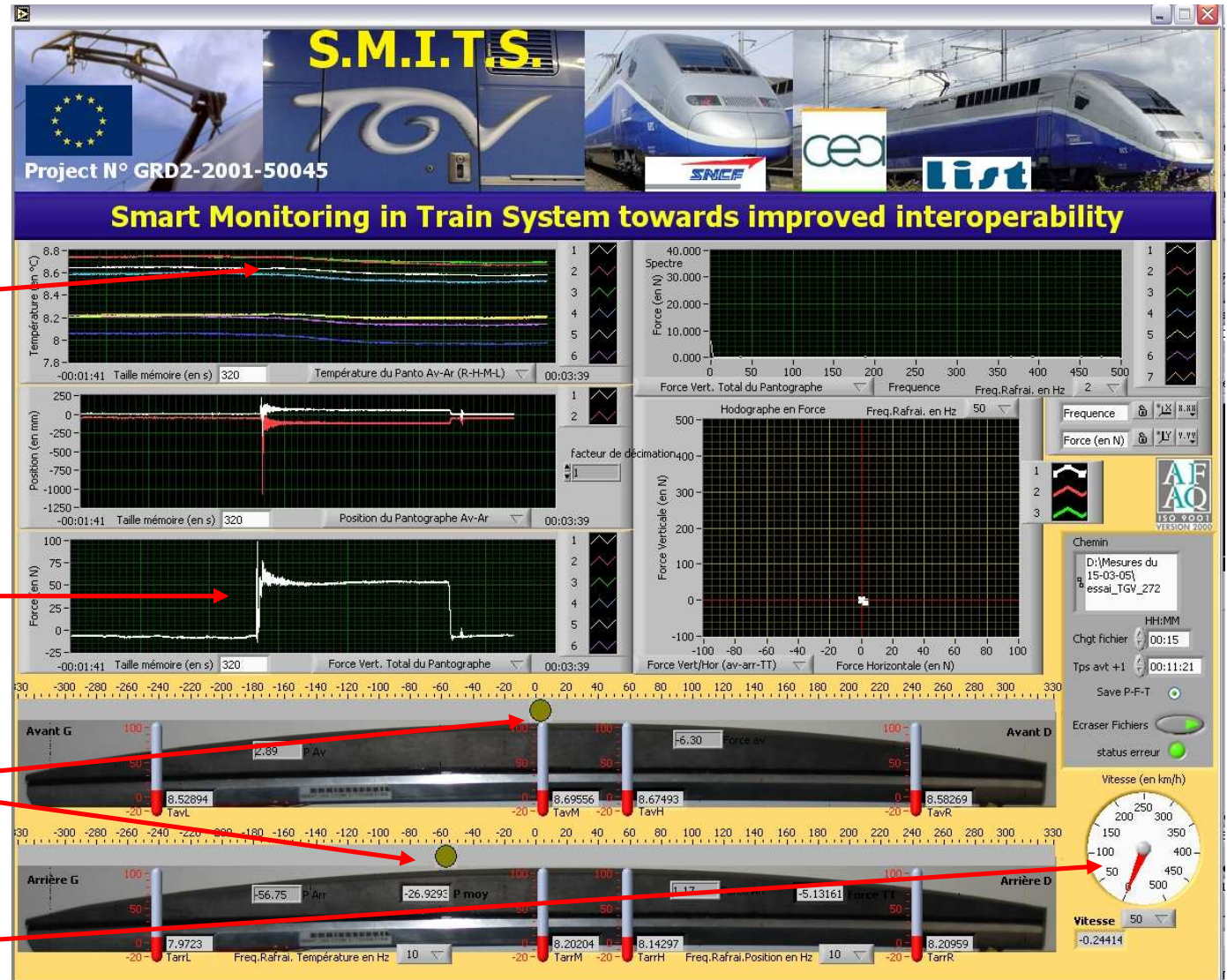
- **Moreover, (F, x, T) data are available on BNC analog outputs for integration into SNCF reference measurement loop**



Client supervisor system overview

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temperatures

vertical force

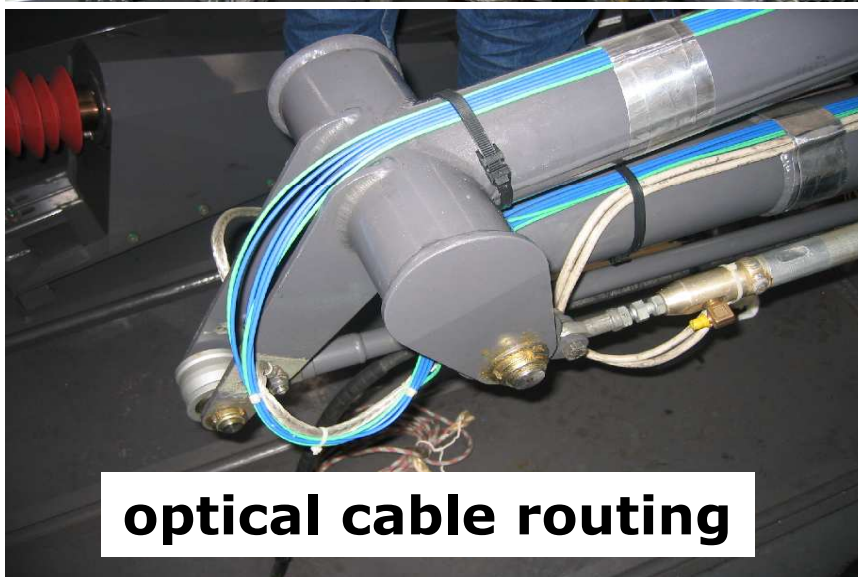
OCL position

speed



Very high speed TGV train installation

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optical cable routing



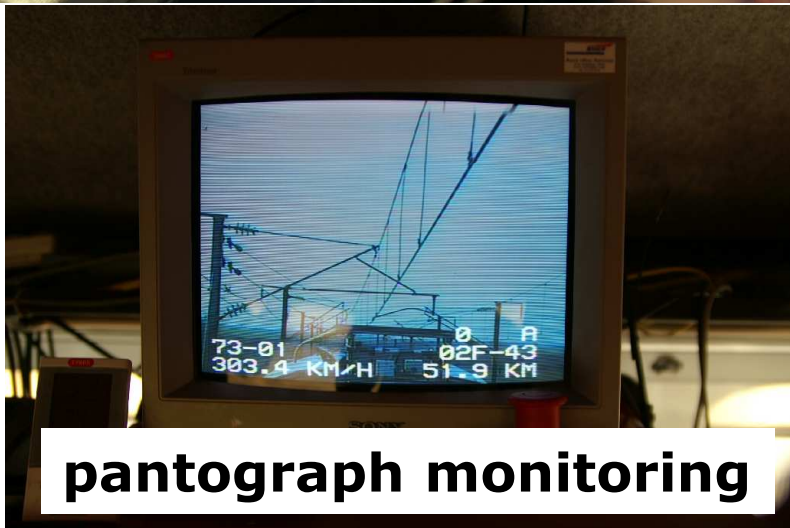
Field tests

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CEA LIST monitoring system



pantograph monitoring

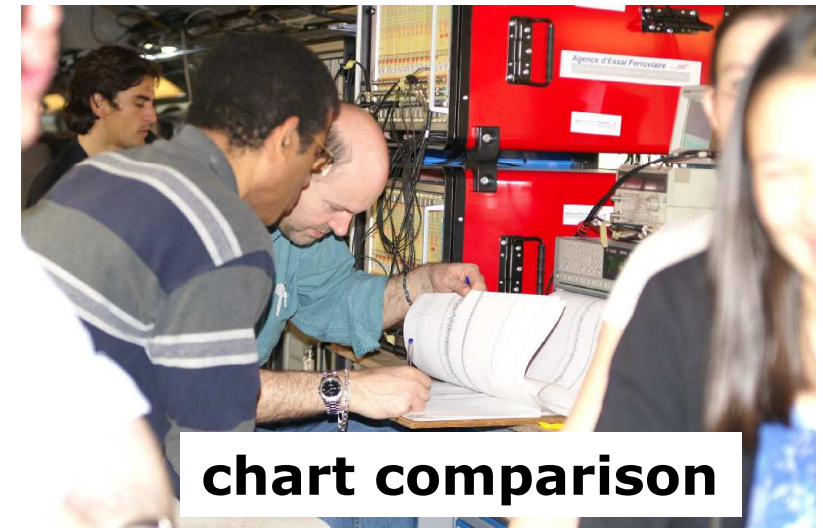


chart comparison



On board TGV installation



Pantograph monitoring at 300 km/h

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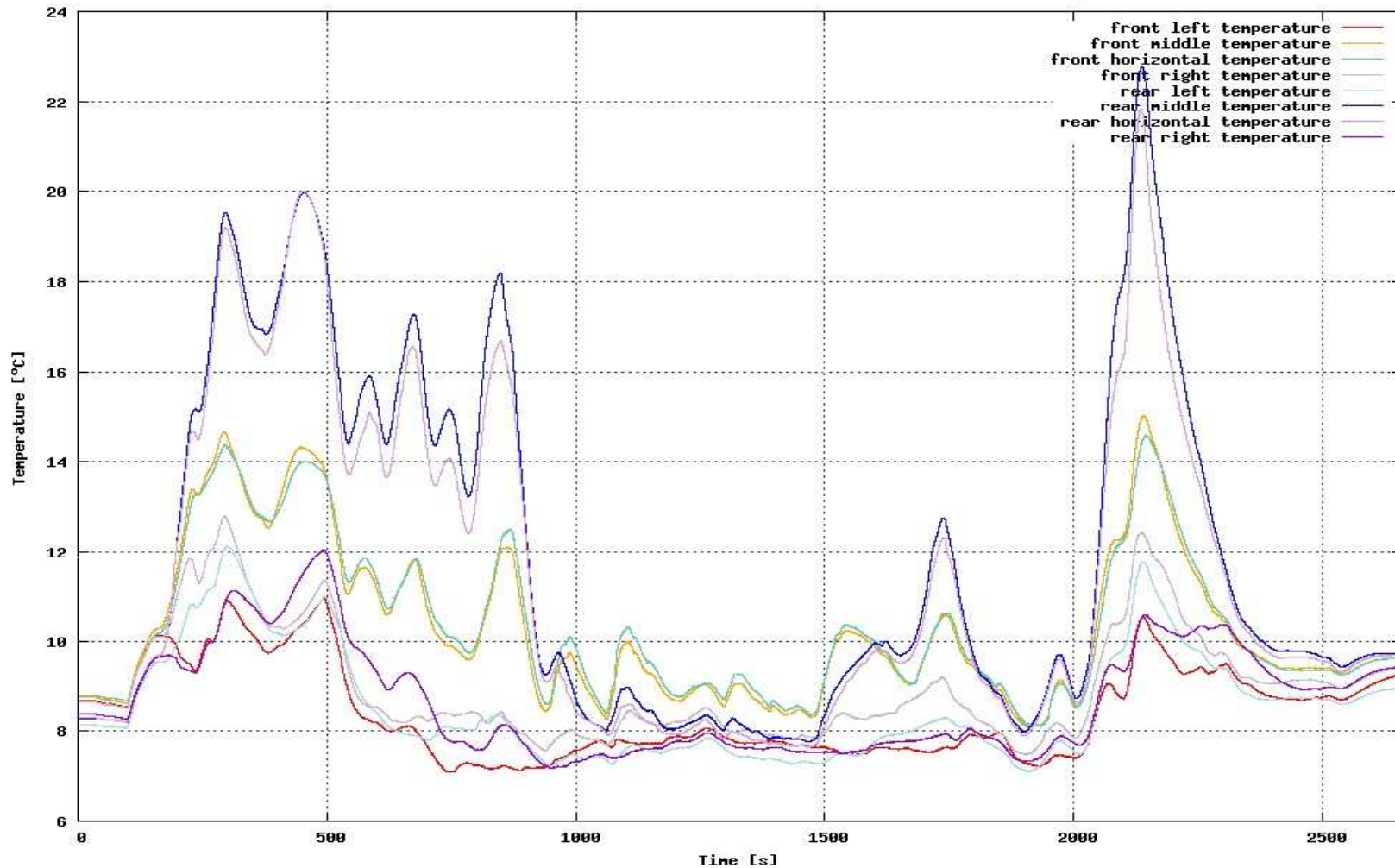
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Temperature measurements

One trip between Paris and Vendôme

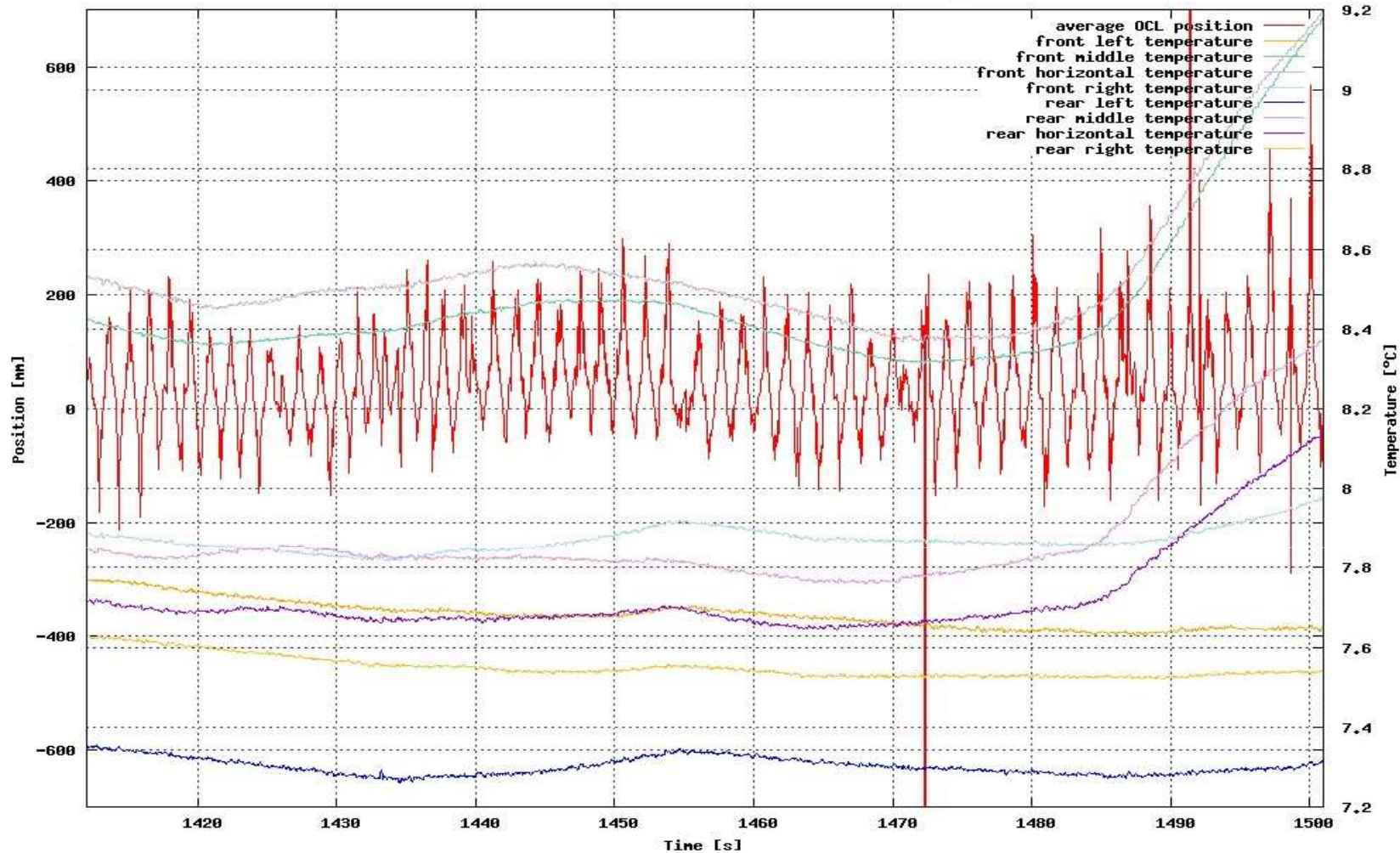
TGV field tests (whole record Paris -> Vendome) - 500 Hz CER measurements averaged @ 20 Hz



6 km OCL position records

1 week 6000 km records between Paris and Vendôme

TGV field tests (PK92 -> PK98) - 500 Hz CEA measurements averaged @ 20 Hz



CEA LIST output project results

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- Wavelength metrological monitoring system performances in agreement with required specifications
 - 1 pm precision achieved
 - 500 Hz "real-time" measurement rate
 - 4 optical lines in parallel
 - Successfully integrated in SNCF measurement loop
- Field tests results
 - Very accurate temperature measurements
 - Realistic vertical force measurements *variations*
 - No failure of the CEA LIST monitoring system



FBG monitoring unit (1/ Bragg FIT)



Bragg-FIT (v1)
COSMUS EU project



*Computer with embedded
opto-electronics*

Bragg-FIT (v2)
SMITS EU project



*Computer
RAID data storage system
opto-electronic module*

Bragg-FIT (v3)
CATIEMON EU project



*Opto-electronic module (19" - 3U)
Laptop + External USB hard disk
either Ethernet or Wifi*

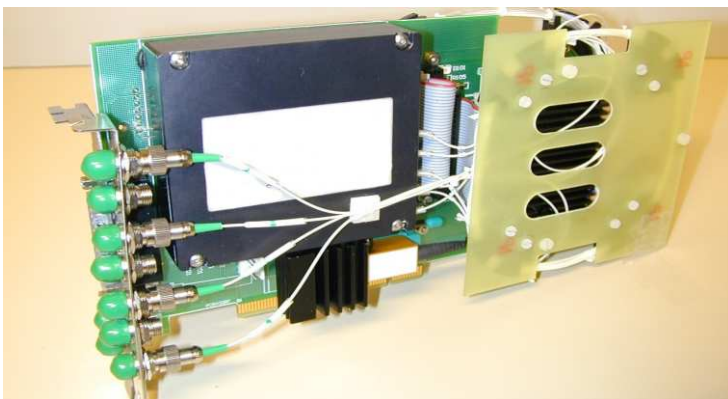
Suitable for the
monitoring of large
structures
(civil engineering, oil
applications, etc.)

Range	~ 20 nm
Resolution	better than 0.1 $\mu\text{m}/\text{m}$ [~ 0.1 pm]
Rate	DC to 500 Hz
Optical lines	max. 6 (in parallel)



FBG monitoring unit (2/ Bragg FAST)

Bragg-FAST (v1)



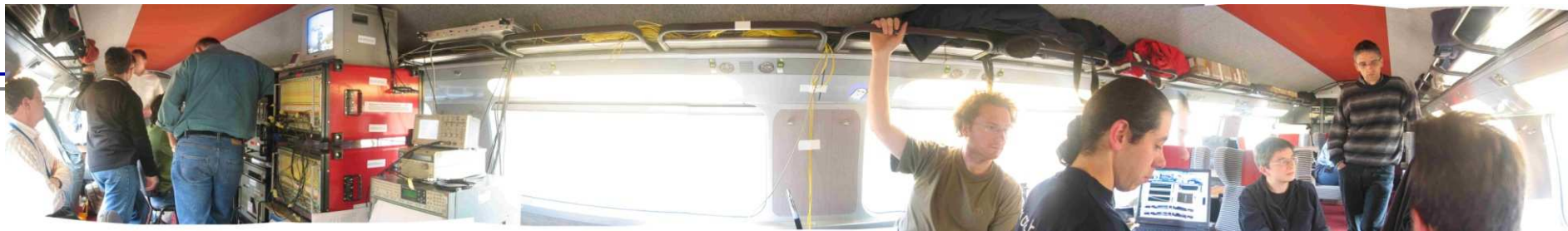
Bragg-FAST (v2)



Suitable for the monitoring of high frequencies or very short events (vibrations, impact detection, etc.)

*Integrated into a 19" 2U industrial rack
Driven using a laptop and an Ethernet link
External USB hard drive for data storage*

Range > 7 nm
Resolution ~ 0.1 $\mu\text{m/m}$ [0.1 pm]
Rate up to **500 kHz**
1 sensor / optical line



Thank you for your attention

Useful links

- **Réseaux Ferrés de France**
 - <http://www.rff.fr/>
- **Eurailtest**
 - <http://www.eurailtest.fr/>
- **Union Internationale des Chemins de fer**
 - <http://www.uic.asso.fr/>
- **European Railway Agency**
 - <http://www.era.europa.eu/>
- **European Commission**
 - <http://ec.europa.eu/>
- **CEA, LIST and Digiteo Labs**
 - http://www.cea.fr/english_portal
 - http://www-list.cea.fr/gb/index_gb.htm
 - <http://www.digiteo-labs.fr/>
- **Catiemon EU project website**
 - <http://www.catiemon.info/>
- **White Paper: "European transport policy for 2010: time to decide"**
 - http://ec.europa.eu/transport/white_paper/documents/doc/lb_texte_complet_en.pdf
- **World rail speed record 574.8 km/h [357.16 mph]**
 - <http://www.record2007.com/>

