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Federal Office of Transport

Programme Energy Strategy 2050 For Public Transport

Project WindowWAVE:

034 Windows with a low U value and a high transmission of microwaves (Zugfenster mit kleinem U-Wert und hoher Mikrowellentransmission)

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HIGHLIGHTS:

- **Simulation and measurement of new windows all allowing mobile telecommunication by laser treatment**
- **Up scaling of the process for the production of large windows**
- **Measurement of the thermal impact due to the laser treatment**
- **Installation of the treated windows on a train RABe 525 NINA from BLS**
- **Attenuation measurement by SUPSI and SWISSCOM**

  (large band & existing technologies)

1 Introduction

In order to reduce thermal losses, in many modern trains, the glazing comprises a coating for low emissivity (low-e) and sun protection, for similar purposes as in building sector. These coatings improve the U-value (e.g. thermal performance from 3 to 1.5) of a glass by reducing infrared radiation exchanges between the inside and the outside. In winter, the heat stays inside and in summer, it is possible to reduce overheating problems with a suitable coating. However, because this coating is made of multiple layers including metallic ones, it highly attenuates the transmission of microwaves used in mobile telecommunication. The main body of the train is metallic, therefore a metallic coating on the window closes the faraday cage and electromagnetic waves for telecommunications are not transmitted.

A solution used currently in many modern trains of national and international railway companies, is to install intrain signal amplifiers (repeaters). This solution is technology dependent; a repeater works for a defined range of frequencies. Because of mobile phone standards evolve quickly, repeaters have to be replaced more often than trains. Moreover repeaters are electrical consumers which reduce the energy savings achieved by modern windows.

The solution currently investigated at EPFL-LESO is to modify the low emissivity coating in order to make it transparent to microwaves in a wide range of frequencies.

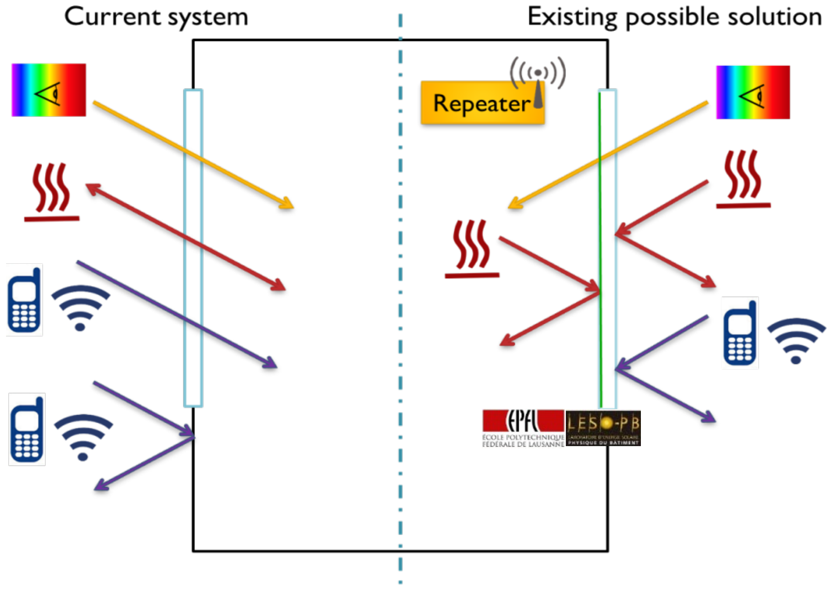


Figure 1 : Structuring the low-e coating would keep the benefit of reducing the heat losses due to infrared radiation while allowing the transmission of microwaves in mobile telecommunication

The high mobility of the conduction electrons present in the metallic layers reflects and strongly attenuates the microwaves. The idea is to interrupt the conductive layer on a sufficiently small length scale with respect to the wavelength in order to avoid this effect.

The table 1 presents frequencies used in different types of mobile communications and the corresponding wavelength.

Network	Frequency / Hz	Wavelength / m	Wavelength / cm
4G/TNT	800E+06	0.375	37.4
2G/3G	900E+06	0.333	33.3
2G/4G	1.8E+09	0.167	16.6
3G	900E+06	0.333	33.3
3G	2.1E+09	0.143	14.2
4G	2.6E+09	0.115	11.5
Wi-Fi	2.5E+09	0.122	12.2

Table 1 Frequencies and corresponding wavelengths used in telecommunication

2 Laser scribing of low-emissivity coating

Commercial glass for energy saving window from AGC Verres Industriels Moutiers was processed. Glass samples with a thickness of 4 mm and a Planibel Low-e Top N+T low-emissivity coating were used. Pieces of tempered glass with arrised edge with a size 500 x 500 mm were prepared to be processed then assembled in double glazing. With these dimensions the attenuation of the radio transmission can be measured.

The laser treatment allows to remove a very small percentage of the low-e coating removed. This is important in order to maintain a low thermal emissivity. This experiment allows us to see the quality and ease of removing a low-e coating using the laser scribing technique.

In order to choose the best configuration, the line spacing of the grid has been varied and the microwave attenuation has been characterized. The figure 5 shows the attenuation response in frequency depending on the spacing of the grid.

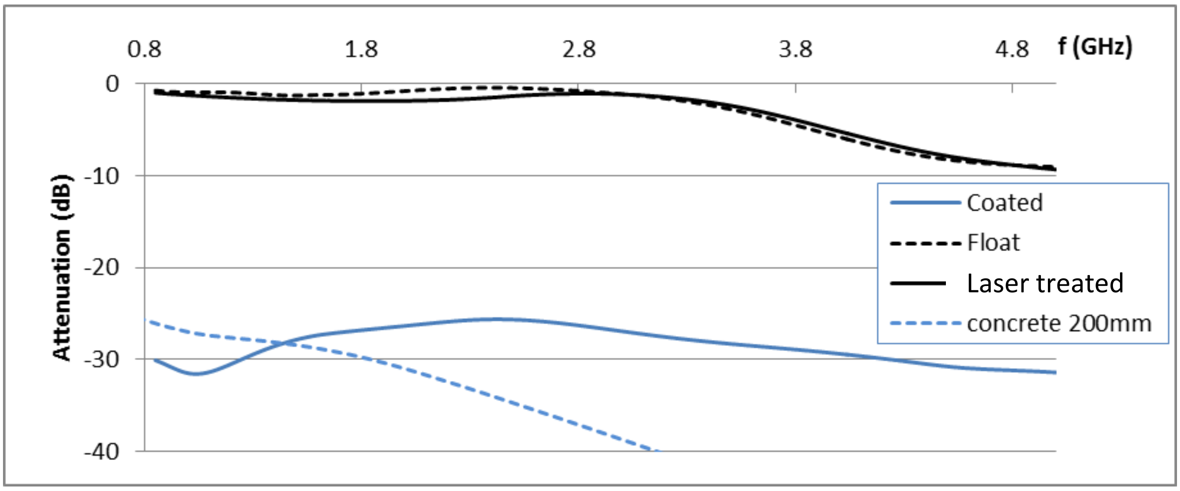


Figure 2 : Measured attenuation of a non-coated window / low e coated window / the same windows after the laser treatment / a concrete wall of 200 mm thickness

Regarding this results, the laser treatment allows to obtain an attenuation comparable to a non-coated windows (±0.5dB) and an attenuation under 5dB in the domain 0.8 to 3.8 GHz. Which is really low compared to a coated window or a concrete wall of 200 mm.

3 Large scale production

By using the large XY table (AGC) and a large scale production have been realized. We have produced 34 windows of a dimension of 1.4m by 1m with the purpose of fitting a NINA train from BLS.

Figure 3 : First series of pilot production with the new process equipment.

Figure 4 : Photographs of a double glazing with laser structured low-e coating, on the right with light at low incidence angle. The scribed lines are barely visible to the eye

As seen in figure 7, laser scribing allow to remove a small part of the coating which allows to keep the low emissivity effect. In addition, it is better for visual appearance. The treatment can be seen only at certain angles of reflection.

4 Thermal efficiency

The U value was measured by Fraunhofer Institute for Solar Energy Systems according to DIN EN 674:2011. The measurement was performed on 800 by 800 mm samples to reduce possible edge effects.

The g value was obtained for different incident angles from 0° to 75° with respect to the standard AFNOR - NF EN 410 and using the method developed by Reber et al.

For the g value the measurement was performed on samples with a dimension of 1200 by 800 mm to avoid edge effects and for three types of glazing: without coating, with full coating and with laser scribed coating. To be comparable, all the samples were composed as follows: 4 mm of float glass (coated or not), 12 mm of dried air, 5 mm of grey glass. The double glazing was filled with dried air to avoid possible errors due to the filling rate of special gases.

The double glazing without coating shows standard U and g values. The low emissivity coating reduces the U value by a factor 1,5. The U and g value modifications due to the ablated area of coating (2,5%) remains below the measurement error (< 2% for the U value and <5% for the g value considering the uncertainty).

	Double glazing without coating	Double glazing with full coating	Double glazing treated coating
		U ($W/m^2.K$) ± 0.04	
	2.89	1.86	1.87
ϕ (°)		g (ϕ) ± 0.02	
0	0.53	0.37	0.37

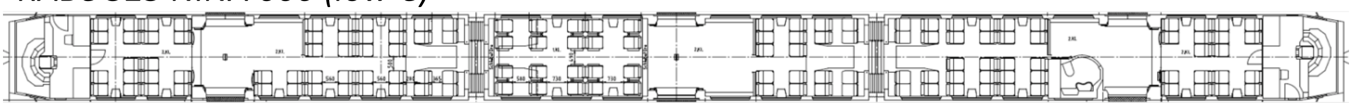
Table 2 : U and g value for different types of windows

However, the measurements prove the small impact of the laser treatment on the thermal quality of the window. Moreover by using noble gas instead of air the thermal quality can be increased significantly.

5 Train NINA equipped with new glazing

A train retrofit project was carried out by the railway company BLS. To achieve good insulating properties, modern window with low-e coating had to be installed. In order to allow mobile telecommunication in the carriage a repeater solution could have been used but would have represented electrical and financial costs. To achieve both, better insulation and telecommunication without added repeater technology, prototyped windows were installed on a RABe 525 NINA train. This train was used as a real case scenario to analyse the efficiency of the new technology with regards to existing telecommunication network.

RABe 525 NINA 006 (low-e)



RABe 525 NINA 0xx (std)

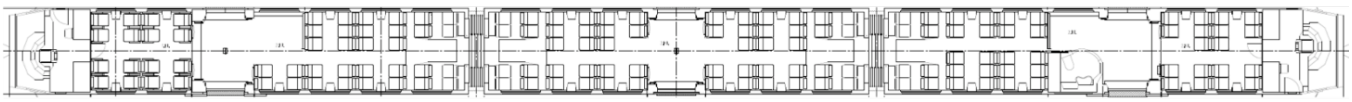
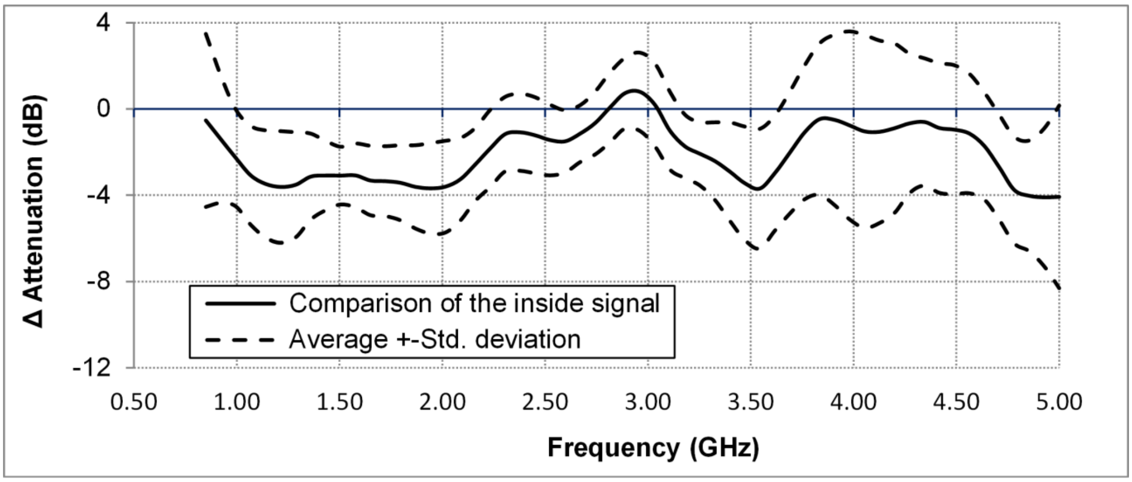
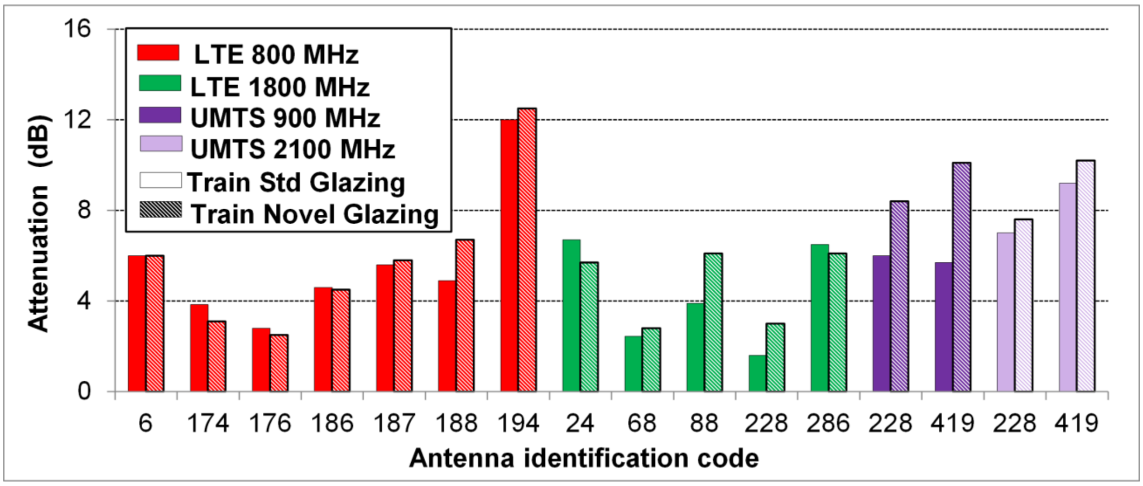


Figure 5 Train NINA from BLS equipped with new windows (laser scribed) / Drawing of the carriage for the standard and equipped NINA train

A measurement campaign was carried out on two stationary trains, one equipped with standard non-coated windows and one equipped with the prototyped windows. Two measurements have been done for each train, one on a wide band of frequencies and a second one, on existing mobile radio signals (UMTS at 900MHz and 2100MHz, and LTE at 800MHz and 1800MHz).



a



b

Figure 9 : Comparison of attenuation signal between a train with novel glazing and one with standard glazing. (a) SUPSI Frequency dependent difference of the average attenuation for polarization vertical and ±45°. (b) SWISSCOM Evaluation of different technologies LTE, UMTS, the bars show the attenuation in signal level from the outside to the inside.

The two trains were measured sequentially and in the same location to ensure a similar angle of incidence. However, it is worth noting that the interiors of the two trains were not identical (e.g.: train compartment separated by walls). This fact may induce a positive or negative deviation on the results.

For both measurements (Fig.9-a,b) the difference of attenuation between the two trains remains in almost all cases below the uncertainty of ±2 dB. This result stands as a proof of good transmission between the outside and the inside of the carriage.

Another measurement campaign was carried out by SWISSCOM to compare the mobile network performance that a user would experience travelling inside a train with the prototyped glazing, compared to a train with standard non-coated glazing. The test train was composed of two coupled RABe 525 NINAs, each one with a different type of windows, and each one with 3 carriages.

Figure 10 Measurement of the actual technologies in a moving train by Swisscom

For a fair comparison of subsequent journeys, the track was sliced into segments of 25 meters and only the average of the samples that fell in each segment was used to calculate the cumulative distribution function (CDF) of each quantity in every trip. The track segmentation was required to avoid unfair effects due to the different speeds of the train in subsequent journeys. Figure 11 shows the CDF of the RSCP (Received Signal Code Power) and the downlink MAC throughput for UMTS 2100.

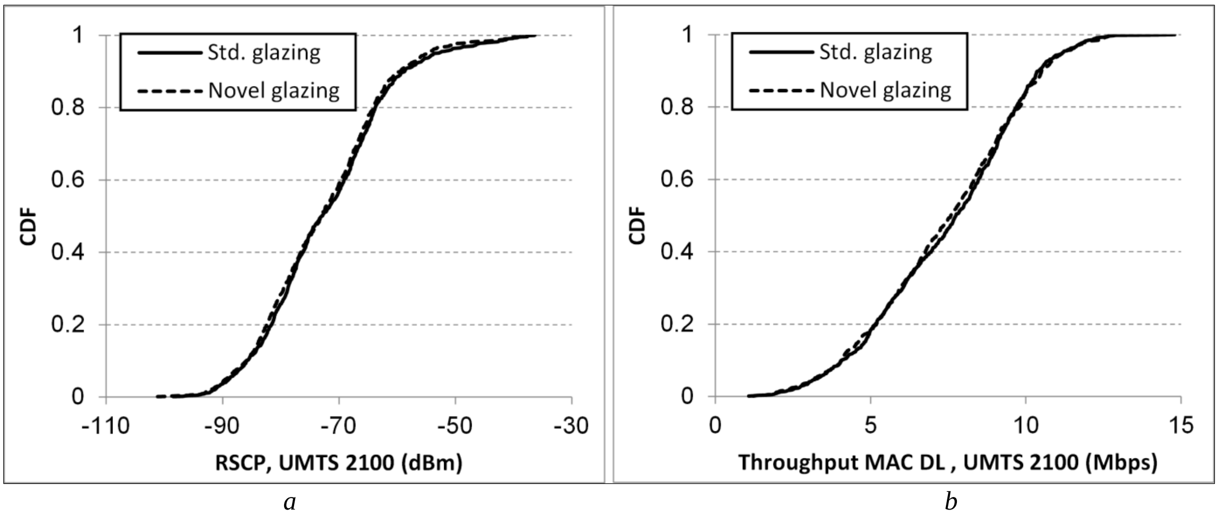


Figure 11: Distribution of the CDF value for the technologies UMTS 2100 . as a function of the attenuation level (a) and of the throughput (b) for the train equipped with novel glazing and the one equipped with standard glazing.

The results are very similar for both trains. The continuous line shows the results for the train with standard windows and the dotted line shows the results of the train with prototyped windows.

This measurement campaign proved that the mobile network performance in a NINA train equipped with the prototype glazing is comparable to that of a standard NINA train with non-coated glazing. Moreover these results are in agreement with those of the stationary measurement.

6 Conclusion

A large-scale production of modern windows allowing mobile telecommunication was presented. Large-scale glazing with a wide band pass Frequency Selective Surface (FSS) of commercial low emissivity coatings has been produced by laser processing. Thermal properties (U, g) have been measured and show almost no deviation compared to a fully coated glazing. This result has been reached by optimizing the scribing process to reduce the percentage of engraved area. A quality control has shown that the attenuation remained under 3dB in the telecommunication frequency domain. Compared to a standard coated window with attenuation up to 30 dB higher than that of the non-coated window, this result is outstanding. As a proof of reliability, an entire train has been equipped with prototype windows and tested in real conditions. This study shows a high signal transmission in the prototype window equipped train compared to one with standard windows (<1.8dB). The measurements of attenuation for the wide band-pass and for current technology (LTE and UMTS) are almost not affected by the scribed coating. The presented glazing with a wide band pass FSS made by laser treatment can be a promising alternative to the repeater.

Publications:

O. Bouvard, M. Lanini, L. Burnier, et al. **Structured transparent conductive coatings with dual spectral selectivity across the terahertz region**, *submitted to Applied Physics A, 2016*

Luc Burnier1*, Matteo Lanini2, Olivia Bouvard1, et al. **Novel energy saving glazing with a wide band-pass FSS allowing mobile communication: Upscaling and characterization,** *submitted to IET Microwaves, Antennas & Propagation*

Press (selected examples):

Communiqué de presse EPFL : http://actu.epfl.ch/news/un-vitrage-de-train-conjugue-reception-mobile-et-i/

Tribune de Genève 29/08/2016 : http://www.tdg.ch/suisse/Nouveau-vitrage-pour-mieux-telephoner-en-train/story/14638923

Bhnonline: http://www.bahnonline.ch/bo/blog/13611/bls-nina-flotte-epfl-entwickelt-energieeffizientes-mobilfunkdurchlaessiges-fensterglas-zuege.htm

CQFD la première: Mardi, 30 août 2016 à 10:04 Réception mobile dans les trains: une solution de l'EPFL,
Le matin 29/08/2016 :http://www.lematin.ch/suisse/Nouveau-vitrage-pour-mieux-telephoner-en-train/story/14638923

Motortippss : http://motortipps.ch/eth-lausanne-mit-innovativer-glas-erfindung/

Newatalas: http://newatlas.com/train-windows-mobile-phones/45145/

Mobile today : http://mobiletoday.ir/2016/08/train-windows-that-combine-mobile-reception-and-thermal-insulation/

Etc.

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