Wireless Attenuation by Energy Efficient Windows in the 8-12.5 GHz region

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Abstract

Measurements are presented of wireless propagation into buildings via standard double glazing and via heat isolating (Low Emissivity) double glazing in the region 8-12.5GHz. Standard double glazing attenuates the signal in line with results published elsewhere. Heat energy efficient double glazing, however, at least 20dB more than the standard glazing of the signal does not pass. The reason for this poor propagation is outlined and a propagation model for the heat isolation window is presented.

Introduction

Low emissivity glass is widely used in double-glazed windows and doors, due to its ability to reflect re-radiated solar energy back into a building. The low emissivity is achieved by adding coatings, usually to the inside of one or both of the panes in a double glazed window, and, in some cases, by adding an inert gas, typically argon, krypton, xenon, CO_2 or sulphur hexafluoride, instead of a vacuum between panes. Coating a glass surface with a low-emittance material reflects a significant amount of radiant heat, thus reducing the total heat lost through the window. The principle of operation means short wavelength radiation (the visible spectrum) is transmitted, at least 90%, through the pane, but longer wavelength radiation is reflected. The coating thickness varies from about 10-400 nm. The coating materials are usually silver or tin oxide, both of which also have good electrical conductive properties. Low electrical resistivity (~10^{-4} ohm cm) yields low thermal emittance, ideal for window insulation and prevention of radiative cooling, but bad for electromagnetic propagation. The coatings typically behave as metals to light of wavelength above 1 µm.

In literature glass has a permittivity around four over a wide frequency range and for various glass manufacturers, a negligible loss factor and very low conductivity. Consequently, the poor propagation

The work described here looks at propagation in the frequency range of 8GHz – 12.5GHz, which is of interest to UWB. It will be shown that the extra coating reduces the transmission by about 30dB across all frequencies.

Experimental Setup

The experiment was carried out indoors, in a corridor in the cellar of the University of Applied Sciences and Arts in Hannover, which was well shielded by thick walls, so that broadcast services had no big influence on the experiment. The window under test was placed in a specially constructed wall between the transmitter and receiver. The rest of the wall consisted of a timber frame and foil-backed insulation, similar to wall construction in a timber framed house. Two similar horn antennas, one were used to perform the investigation of signal propagation in this X-Band (8 GHz – 12.5 GHz) frequency range, with the defined minimum distance to achieve far-field characteristics for antenna measurements. Thus, a majority of the test signal is transmitted directly through the window and not by other propagation paths. A diagram of the wall is illustrated in Figure 1(a). The measurement series include both linear polarisations.

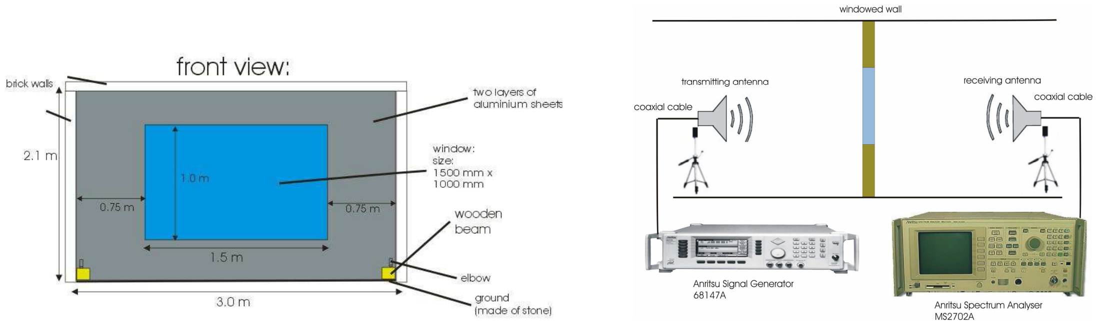

Figure 1 Wall cross-section (left) and test set-up (right)

Two types of windows, with identical dimensions, 4 mm thick glass with a 12mm air-gap, were investigated with this setup. The first window is double glazed with standard float glass and the second window is also double glazed, but with a low emissivity layer on the inside pane on the vacuum side. First of all, measurement system is characterised with no window present, over the whole frequency range. This means that the parameters of an antenna frequency dependency, such as the gain, directivity, radiation characteristic and input impedance may be characterised, as well as the attenuation of coaxial cables. Then a measurement series is carried out with windows present. The differences of the detected signal strengths may then be attributed directly to the poorer propagation caused by the window under test.

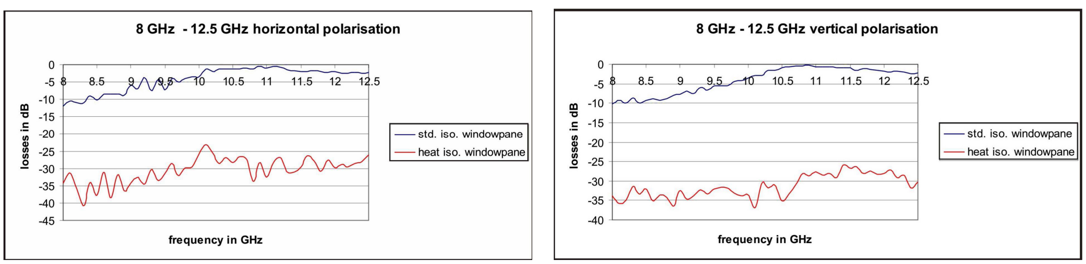

Figure 2 Relative performances of two window types

Results

As mentioned earlier, the results are measured relative to the losses incurred when no window was installed in the wall. The results for the standard isolation window can be compared with trends identified in previous work, such as by the NIST (National Institute of Standards and Technology). But the losses around 8GHz are worth examining. Inaccurate measurements, unexpected or abnormal wave propagation are unlikely to be the reason for this result, because the horn antennas utilised were very close to the window (0.5m). Therefore the transmission line between transmitter and receiver is very short and only obstructed by the window itself. Also, horn antennas have narrow lobes, resulting in a very good directivity. The explanation lies more likely in constructive and destructive interference patterns due to the 4mm glass pane window thickness and their 12mm separation. This is analysed in more detail in the next section, where the dielectric constant of glass is also taken into account. A similar effect is visible in the case of the heat isolation window, but the analysis (later) is slightly different, due to the dominant reflection and transmission coefficients on the coated glass –air interface.

The incident angle is normal, so reflected waves (especially in the case of the low emissivity window, where more than 99% is reflected) will propagate directly back to the signal source and influence new radiated waves coming from the transmitting antenna. Note that multiple reflections occur, because the complete window has four boundaries (albeit one dominant reflecting boundary, in the case of the coating in the Low Emissivity case) and reflected waves will be generated on each of them. Destructive superposition of this cluster of reflected waves would effect the overall transmission of energy through the window. This is the reason proposed for the oscillatory trend in the heat isolation window, compared with the standard window.

Multi-path Analysis (Low Emissivity Case)

The periodic element in the heat isolation window attenuation may be explained as follows. Let T_1, T_2, Γ_1, Γ_2, be the transmission and reflection coefficients for the first and second panes respectively (for simplicity, it is assumed that the reflection only occurs at one of the panes interfaces, but it is easy to extend the analysis to both interfaces). It can be seen from comparison with that the standard float glass panes that $T_1 >> T_2$, and $\Gamma_1 << \Gamma_2$. Also, the low emissivity coating is assumed to be on the inside of pane 2 (propagation path is outside to inside the building).

Let the test signal be represented by $e^{j\omega t}$.

After propagation through pane 1, the signal may be represented by $T_1 e^{j\omega t}$. A significant part of this signal $\Gamma_2 T_1 e^{j\omega t}$ will be reflected back by the low emissivity coating, but some, $T_2 T_1 e^{j\omega t}$, will propagate through the glass. The reflected portion will be incident on pane 1 and the major part of this ($\Gamma_2 T_1 2 e^{j\omega t}$) will propagate back through the pane and be lost. The remainder ($\Gamma_1 \Gamma_2 T1 e^{j\omega t}$) will reflect back to pane 2 and ($T_2\ \Gamma_1\ \Gamma_2 T_1 e^{j\omega t}$) will propagate through. It is possible to follow this argument through for more reflections from panes 1 and 2, but as the reflection coefficient for pane 1, Γ_1, is small, these are neglected here.

The two signals incident on the receiver after pane 2 are then given by:

$T_2 T_1 e^{j\omega t} + T_2\ \Gamma_1\ \Gamma_2 T_1 e(^{j\omega t+\phi})$

Where ϕ is used to denote the phase difference due to the extra path (equal to two times the pane separation or 24mm) traversed by the second part of the signal. This expression may then be written as:

$$T_2 T_1 e^{j\omega t}\ (1 + \Gamma_1\ \Gamma_2 e^{j\phi})$$

The $e^{j\phi}$ term is fixed for any given wavelength, but will vary as the wavelength varies, defined by the fraction of wavelength remaining in the 24mm traversal. This variation can be seen in the low emissivity measurements, but, as expected, not in the standard float glass.

Multi-path Analysis (Reflections in the standard window)

A similar analysis may be applied to the standard glass, although in this case there is no dominant reflection or attenuation interface, i.e. $T_1 = T_2 = T$, and $\Gamma_1 = \Gamma_2 = \Gamma$. This analysis only includes paths with double or no reflections and treats reflections at both glass-air interfaces on each pane. Paths with higher numbers of reflections should contribute a negligible effect. It is easy to see then that the received signal is given by

$$r(t)=T^2e^{j\omega t} + T^2\,\Gamma^2e^{j(\omega t+\phi_1)} + T^2\,\Gamma^2e^{j(\omega t+\phi_2)} + T^2\,\Gamma^2e^{j(\omega t+\phi_3)} + T^2\,\Gamma^2e^{j(\omega t+\phi_4)}$$

So the path may be described by

$$h(t)= T^2\,(1+ \Gamma^2e^{j\phi_1} + \Gamma^2e^{j\phi_2} + \Gamma^2e^{j\phi_3} + \Gamma^2e^{j\phi_4})$$

where ϕ_i denote the phase differences due to the extra paths of 8mm, 24mm, 32mm and 40mm, traversed by the reflected parts of the signal.

The $e^{j\phi_i}$ term is fixed for any given frequency, but will vary as the frequency varies.

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