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# [N480] The use of MLS based methods for characterising the effectiveness of noise barriers and absorptive road surfaces

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## ABSTRACT

Maximum Length Sequence (MLS) methods are currently being specified for a wide range of applications including test methods for characterising the performance of noise barriers. The relative ease of measurement, including the absence of calibration and high noise immunity, make the method particularly attractive for in-situ measurements. The paper reviews TRL experience in exploring and using the method for characterising sound absorption and sound transmission of a range of noise barriers and road surfaces. The experimental investigations were carried out for the Transport Research Foundation. For the measurement of sound absorption some difficulties have been experienced with reflective samples. It is concluded that the method is likely to prove inaccurate for samples with low sound absorption. The measurement errors involved in characterising sound transmission are relatively small; however, anomalous results can result where discrete air gaps occur.

**KEYWORDS**: MLS, noise barriers, absorption, transmission

## INTRODUCTION

Maximum Length Sequence (MLS) methods [1] are currently being specified for a wide range of applications including methods for characterising the performance of noise barriers and absorptive road surfaces. The relative ease of measurement including the absence of calibration and high noise immunity make the method particularly attractive for in situ measurements. The methods have been used in the recently published CEN Technical Specification for provisional application in characterising the in situ performance of sound absorption and sound transmission of noise barriers [2] for a range of angles of incidence. An ISO test for absorption at normal and an oblique angle of incidence has been developed for characterising the acoustic performance of road surfaces under static conditions [3] and TRL has explored the application of the MLS approach to the dynamic characterisation of surfaces using a mobile experimental rig [4]. More recently work has begun to apply MLS methods to sound diffraction in order to quantify the gains of novel barrier profiles such as multiple edge, T-shape and cylindrical barriers [5]. TRL's unique noise barrier test facility (NBTF) was used in this work.

## ABSORPTION

For the measurement of sound absorption on a road surface, or noise barrier panel at normal incidence, a sound source driven by a signal generator is positioned in front of the surface to be tested and a microphone is located between the source and the surface as shown in Figure 1. The measurement method is based on the assessment of the transfer function between the output of the signal generator and the output of the microphone. This transfer function is composed of two components, one resulting from the direct path (from the signal generator through the amplifier and loudspeaker to the microphone) and a second resulting from the reflected path (from the signal generator through the amplifier, loudspeaker, surface under test to the microphone).

The overall impulse response containing the direct and reflected sound is measured in the time domain my calculating the cross-correlation between the signal fed to the source and the signal from the microphone. This overall impulse response consists of the impulse response of the direct path $h_i$ and, after some delay due to the longer travelling distance, the impulse response of the reflected path $h_r$.

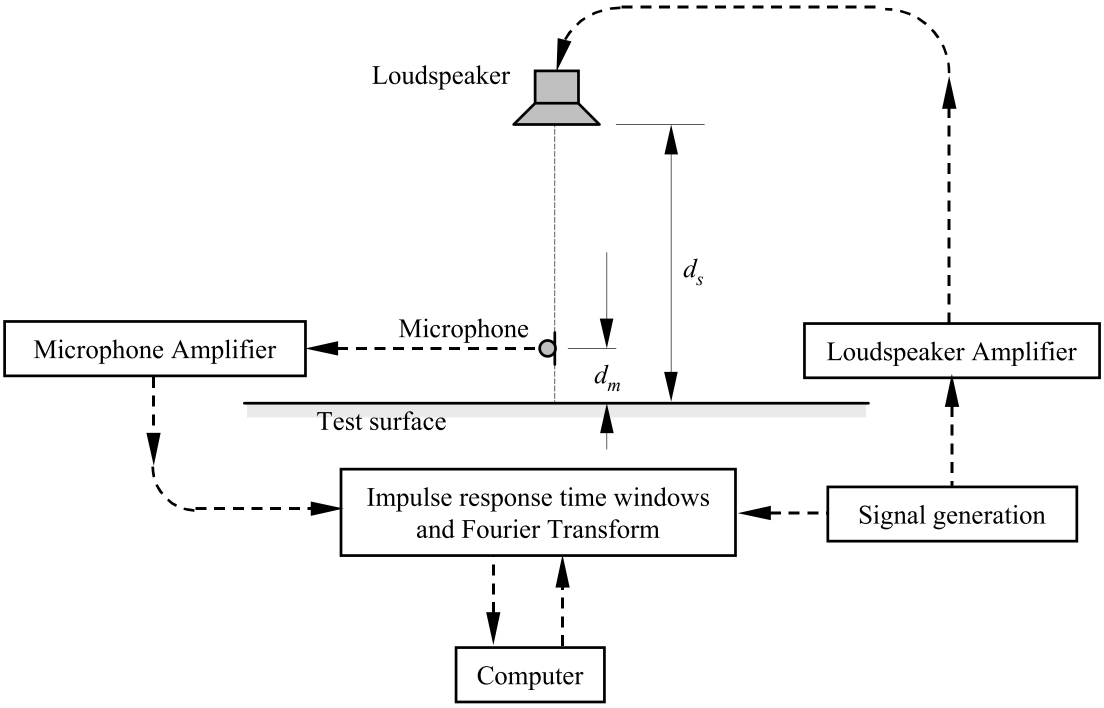


*Figure 1: Location of loudspeaker source and microphone for absorption tests*

With suitable time domain processing by signal subtraction using a free field measurement these responses can be separated. After a Fourier transform, the transfer functions of the direct path $H_i(f)$ and of the reflected path $H_r(f)$ are obtained. The ratio of the modulus of these transfer functions suitably factored ($K_r$) for geometric spreading gives the reflection factor $R(f)$ from which the sound absorption coefficient can be calculated (see below).
Taking into account also this factor $K_r$ for geometrical spreading, the sound absorption coefficient is computed as:

$$\alpha(f) = 1 - \left|R(f)\right|^2 = 1 - \frac{1}{K_r^2}\left|\frac{H_r(f)}{H_i(f)}\right|^2, \tag{1}$$

where

$$K_r = \frac{d_s - d_m}{d_s + d_m}, \tag{2}$$

$d_s$ is the distance between the sound source and the reference plane for the surface under test and $d_m$ is the distance between the microphone and the reference plane for the surface under test. These distances can more conveniently be obtained by measuring the times of arrival $T_i$ and $T_r$ of the maximum values of the direct and reflected pulses in the impulse response. This is simply the result of the distance $d$ travelled by the sound wave being a product of time of travel $T$ and velocity of sound $c$. Thus $K_r$ can be expressed as

$$K_r = \frac{T_i}{T_r} \tag{3}$$

The method considers that the non-specular reflected component is absorbed so that the sound absorption coefficient may be slightly overestimated.

## Limitations

Figure 2 shows typical normal incidence absorption spectra for absorptive and reflective aluminium barrier panels. The highly absorptive sample shows a smooth variation with frequency over much of the measured frequency range. However, a notable feature of the reflective sample is the erratic nature of the coefficients at low levels of absorption that suggested measurement errors. An analysis of these errors is given below.
From equation (1) the variance in the mean of the dependent variable given the variance in the mean of the independent variable is given by:

$$\begin{aligned}\sigma_\alpha^{\ 2} &= \left(\frac{\partial\alpha}{\partial H_i}\right)^2 \sigma_{H_i}^{\ 2} + \left(\frac{\partial\alpha}{\partial H_r}\right)^2 \sigma_{H_r}^{\ 2} \\ &= \left(4.5\frac{H_r^{\ 2}}{H_i^{\ 3}}\right)^2 \sigma_{H_i}^{\ 2} + \left(-4.5\frac{H_r}{H_i^{\ 2}}\right)^2 \sigma_{H_r}^{\ 2}\end{aligned} \tag{4}$$

Figure 3 plots the fractional error defined as the standard error of the absorption coefficient divided by the absorption coefficient ($\sigma_\alpha/\alpha$) for the range of $\alpha$ from 0.01 to 0.99. It is assumed that the standard error is 1% for the direct FFT amplitude and that the standard error of the reflected amplitude is 0.05 of the direct amplitude.

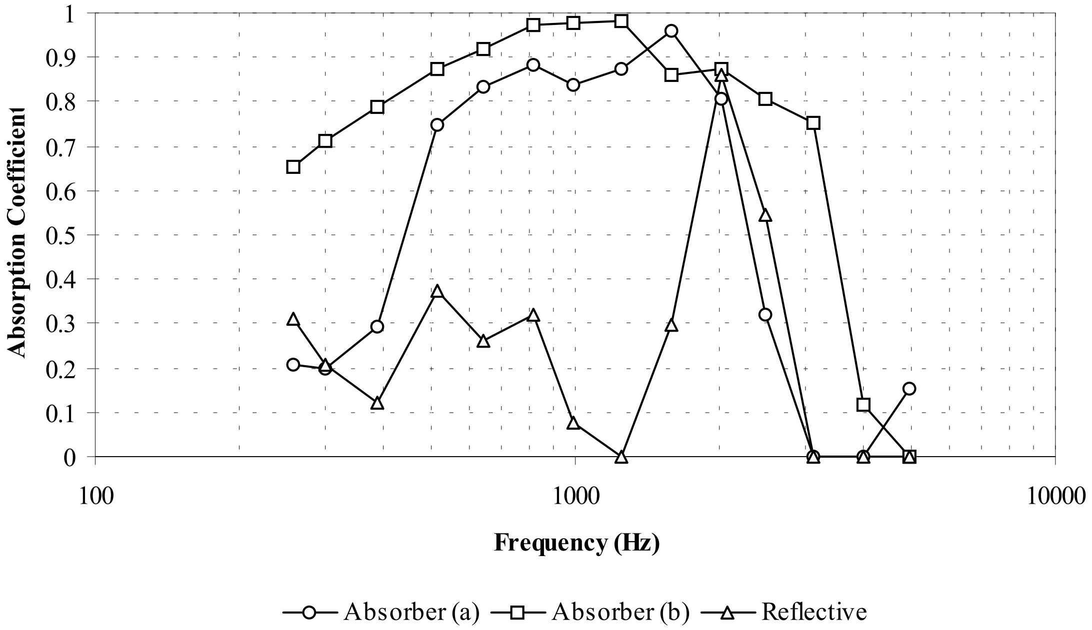


*Figure 2: Sound absorption coefficients for absorptive and reflective absorptive barrier panels at normal incidence*

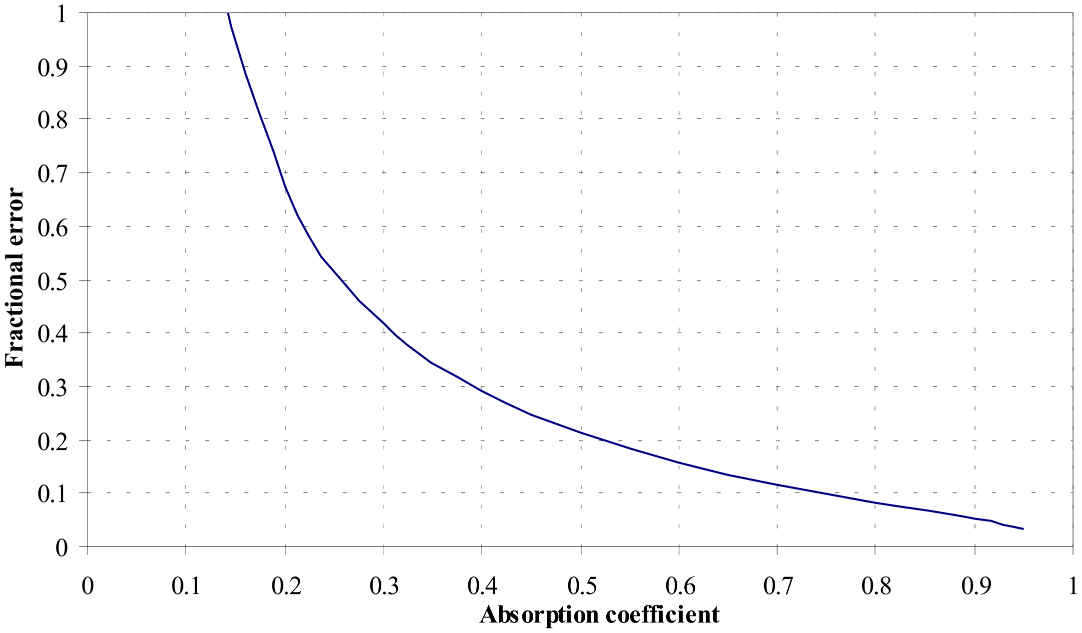


*Figure 3: Fractional errors in MLS measurements assuming 1% and 5% measurement errors in the direct and reflected transfer functions respectively*

The estimated error for the reflected pulse is larger than the direct pulse due to the residual of the direct pulse after subtraction to isolate the reflected pulse, parasitic reflections from panel and post edges and time window edge effects due to non-zero values at window boundaries. This will produce oscillation typically at frequencies <1 kHz [6].

At low values of $\alpha$ the fractional error can be large while as $\alpha \to 1$ the error becomes small. It can be seen from Figure 3 that for an acceptable fractional error the sample has to be at least mildly absorbing. Thus the size of the absorptive peaks in a porous sample can be determined with acceptable accuracy but the errors in determining the absorption of a reflective surface such as a non-porous road surface or reflective panel cannot be determined so precisely. Such errors are clearly indicated when the measured absorption coefficient becomes negative. In these cases the best estimate of the value of the coefficient is zero.

It should be noted that large errors were noted when a highly reflective acrylic barrier panel ($\alpha$ close to 0.0) was tested at the same location in Grenoble by 8 independent measurement teams as part of the Adrienne research project [7]. For this purpose each team averaged results over 9 angles of incidence. The average absorption coefficient at 1 kHz varied in the range -0.2 to 0.2. At lower frequencies the range was even larger. In contrast results for an absorptive barrier panel were more comparable. At 1 kHz $\alpha$ varied from 0.7 to 0.8.

## TRANSMISSION

For the measurement of sound transmission loss (airborne sound insulation) of a noise barrier panel the loudspeaker is positioned in front of the traffic face of the surface to be tested and a microphone is located behind the barrier as shown in Figure 4(a). The measurement method is based on the assessment of the transfer function between the output of the signal generator and the output of the microphone with and without the barrier present (Figure 4(b)). In addition to the sound transmitted through the barrier the sound from the source can reach the microphone by being diffracted over the top of the barrier. Note that diffraction around the sides of the barrier is also possible but because of the larger path lengths typically involved this component will be a considerably weaker signal and will arrive much later. With suitable windowing the transmitted component of the impulse response $h_t$ can isolated and the corresponding transfer function $H_t$ obtained by Fourier transform. The measurement is repeated without the barrier present with identical loudspeaker-microphone separation so that the direct fee-field impulse response can be acquired. The logarithm of the squared ratio of the modulus of these transfer functions gives the sound reduction coefficient, *SR*,

$$SR(f) = -10\log\left[\frac{|H_t(f)|}{|H_i(f)|}\right]^2 \tag{5}$$

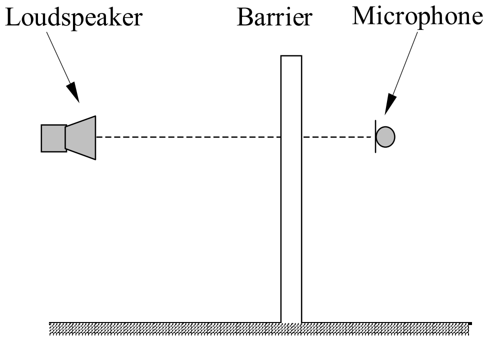
Tests have been carried out at normal incidence on commercial absorptive panels. This involved a free-field measurement at near normal incidence. A small loudspeaker source was placed 1m in the middle of the front face of the barrier at mid height and a microphone was placed on the screened side opposite the loudspeaker.

With the barrier placed between the loudspeaker and the microphone the impulse response consists of the directly transmitted component followed by the diffracted component. It is straightforward to identify the start of the diffracted pulse so that the window of length typically 5ms can be placed so that it contains almost all of the transmitted impulse response. Due to the vibration of the panel some energy may lie outside the window, in which case the sound insulation value will slightly inflated.

## Limitations

The ratio of the transfer functions is involved in the calculation of the *SR* (see equation 5) without the subtraction term (needed in the case of absorption (see equation 1). This indicates that greater precision in the determination of the transmission loss is possible than is the case for absorption. However, errors can arise where air leaks exist in the panels. With poor sealing between panel and post or between the panels themselves there will be sound leakage through the air gaps. In the case of leaky barriers each small gap becomes a small source on the screened side of the barrier with an associated spreading factor dependent on size and shape.

(a) Transmitted component measurement



(b) Free-field measurement

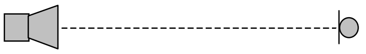


*Figure 4: Test arrangement for sound transmission measurements*

A simple case that can be analysed is where a small gap or hole dominates the sound transmission index so that losses through the barrier material can be neglected. For timber barriers this could occur due to a knot hole or gap due to warping or splitting. In the case of metal or concrete barriers leakage is more likely due to misaligned or missing seals between panels or post and panel. If the largest dimension of the gap is small compared with the wavelengths of interest then hemispherical spreading of acoustic energy from the gap at the rear of the barrier occurs. The analysis in terms of sound intensity, assuming that there is a single gap in a 1m$^2$ area, is as follows:

If $I_o$ is the intensity at unit distance from the source then the intensity at the barrier surface on the source side $I_B$ is given by

$$I_B = \frac{I_0}{d_s^2} . \qquad (6)$$

If the fraction of power transmitted is $T$ and this is concentrated as a point source at the rear of the barrier then the intensity at the receiver is given by

$$I_R = \frac{TI_B}{2\pi d_r^2} = \frac{TI_0}{2\pi d_r^2 d_s^2}, \tag{7}$$

where $d_s$ is the loudspeaker to barrier distance and $d_r$ is the barrier to microphone distance. Note that the thickness of the barrier is considered insignificant.

Without the barrier present the intensity at the microphone is given by

$$I_{R-B} = \frac{I_0}{(d_r + d_s)^2}. \tag{8}$$

So the ratio of intensities with and without the barrier present is given by

$$\frac{I_R}{I_{R-B}} = \frac{T}{2\pi}\left(\frac{d_r + d_s}{d_r d_s}\right)^2 \tag{9}$$

The measured broad band transmission loss $R$ is given by:

$$R = -10 \times \log_{10} \frac{T}{2\pi}\left(\frac{d_r + d_s}{d_r d_s}\right)^2 = -10 \times \log_{10} T - 10 \times \log_{10} \frac{1}{2\pi}\left(\frac{d_r + d_s}{d_r d_s}\right)^2 \tag{10}$$

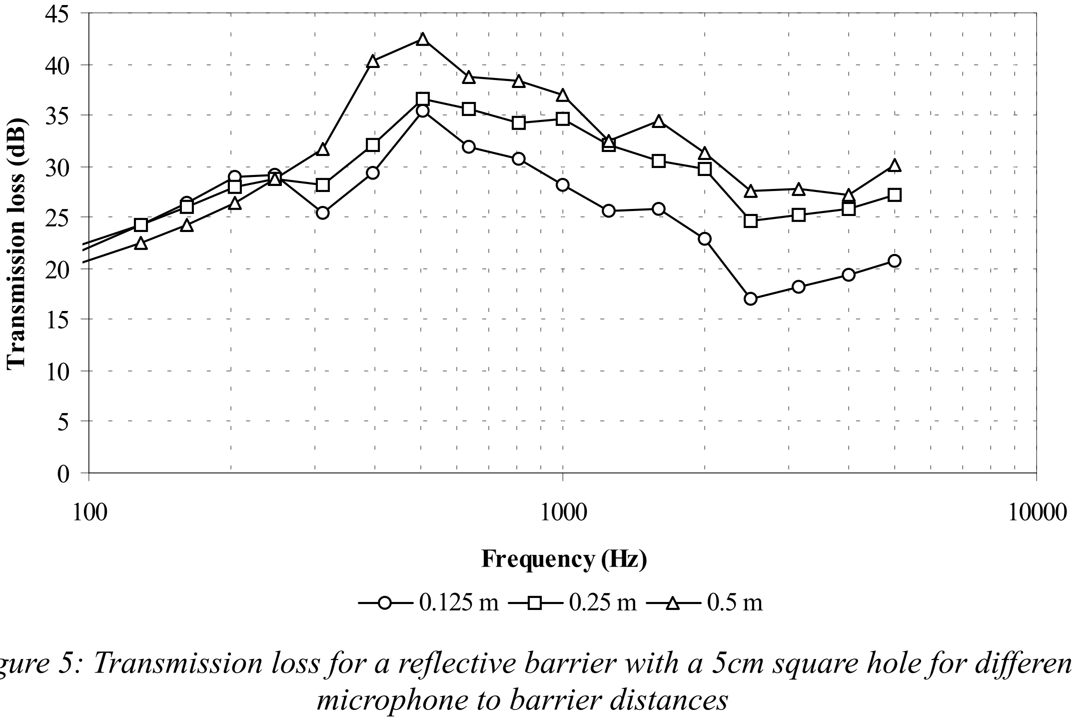


*Figure 5: Transmission loss for a reflective barrier with a 5cm square hole for different microphone to barrier distances*

where $-10\times\log_{10}T$ is the required transmission loss and the second term is the distance correction term. If $d_s$ is kept constant at 1m and $d_r$ is varied the correction term varies from 11.1dB for $d_r$ = 0.125m to 1.6dB when $d_r$ =0.5m, that is a 9.5dB difference. At a distance of

0.25m the correction is 6.0dB i.e. a difference of 5.1dB. Figure 5 shows the transmission loss At frequencies of 400Hz and above the measured differences in transmission loss for different positions are broadly comparable with the predictions of equation (10).

Clearly there is a need to be aware of this effect when measuring near air gaps. The MLS technique is more appropriate for testing the performance of homogeneous sheets of materials without significant gaps. Under these conditions test results for a wide range of materials based on weighted sound reduction indices (i.e. single number ratings of airborne sound insulation) show a good correlation with the overall transmission losses obtained using standard reverberation room techniques [8].

## CONCLUSIONS

The experience with MLS techniques has indicated the advantage of the technique particularly the high noise immunity which enables roadside measurements to be carried out without road closures being necessary.

However for the measurement of sound absorptive using signal subtraction techniques the errors increase significantly at low values of sound absorption making the technique inaccurate for samples with such properties.

In the case of measurements of sound transmission thorough panels the errors are likely to be relatively small except when measuring near significant air gaps. In this case the distance of the microphone from the gap has been shown to have a significant effect on the result.

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