Measurements on low noise road surfaces

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ABSTRACT
Low Noise Roads (LNR) are commonly used as an high efficient noise abatement measure direct at the source. A lot of different types of road surfaces, dense and open porous, with full thickness and thin layers, made of asphalt and cement concrete, have been developed. Since the EU–Project SILVIA a systematic classification method for the quantity of noise reduction is under development including different direct measurement methods like Statistical Pass-by Method, SPB (also with Backing Board or with Array technique), Close Proximity Method, CPX, and indirect measurement methods for texture, acoustical absorption and air flow resistivity of the surface. All these methods have advantages and drawbacks and are having systematic and random errors. But there are also principal, physical and non–physical limits of usage. For a special thin layer surface DSH–V5, used on urban roads as well as on motorways, problems with measurements and the estimation of the noise reduction and its acoustical durability will be discussed as an example. The general implementation procedures for correction factors for LNRs in national and international road noise emission models like RLS and CNOSSOS–EU will be remarked.

Keywords: Road Noise, Measurement
I–INCE Classification of Subject Numbers: 11.7.1, 13.2

1. INTRODUCTION
There are a lot of Low Noise Road surfaces, LNRs, developed within the last decades. In the late 80’s of the last century the first open porous surfaces made of asphalt were built in. The porosity of this first generation surfaces was not as high as nowadays. In the 90’s surfaces with special texture were built in. The use of thin surfaces was a bit later in Germany then in some European countries. With the economic recession of the late 10’s of this century an economic stimulus package, Konjunkturpaket II was created. One of the financial aids of this package was the building of LNRs on urban roads. A lot of different LNRs were developed in these years.

2. LOW NOISE SURFACES

2.1 Definition
What is a LNR? The definition of LNR in Germany is directly linked with the directive of noise protection on roads, Richtlinien für den Lärmschutz an Straßen, RLS–90 (1). The reference surface of this directive is a non grooved mastic asphalt, nicht geriffelter Gussasphalt. A LNR could be defined by having an emission level of at least 2 dB below the emission level of the reference surface. Normal stone mastic asphalt, SMA, or normal asphalt concrete, AC, or exposed aggregate cement concrete, EACC, are therefore defined as LNRs.

Some surfaces like porous asphalt concrete, PAC, or some kinds of thin asphalt layers, TALs, are having an noise emission level even lower than the normal LNRs. But there are still big problems on using these road surfaces. The main problem is their low acoustical durability compared to LNRs with only 2 dB less emission level.

Of course there are also existing road surfaces with an higher emission level of noise like transverse brushed cement concrete or roads made of cobblestones.

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2.2 List of German LNRs

In Table 1 there are five LNRs listed which have an official reduction level stated in the last column of the Table.

<table>
<thead>
<tr>
<th>German name</th>
<th>international name</th>
<th>noise reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Offenporiger Asphalt, OPA</td>
<td>porous asphalt concrete</td>
<td>-5 dB</td>
</tr>
<tr>
<td>Splittmastix Asphalt, SMA</td>
<td>stone mastic asphalt, SMA</td>
<td>-2 dB</td>
</tr>
<tr>
<td>Asphalt Beton, AB</td>
<td>dense asphalt concrete, DAC</td>
<td>-2 dB</td>
</tr>
<tr>
<td>Waschbeton WB</td>
<td>exposed aggregate cement concrete, EACC</td>
<td>-2 dB</td>
</tr>
<tr>
<td>Lärmarmer Gussasphalt GA\LA</td>
<td></td>
<td>-2 dB</td>
</tr>
</tbody>
</table>

All LNRs but one are having a reduction of 2 dB according to the reference surface of non grooved mastic asphalt. Porous asphalt concrete is having an official reduction of 5 dB. For new pavements this value is even higher and reaches 8 dB or more. But due to clocking and ravelling of the surface the reduction level is getting less in time. After eight years the value of 5 dB is reached as a mean value and this level is guaranteed for the construction within this time span.

In the upper part of Table 2 there are four LNRs listed, which have so far no official reduction level. But they are already mentioned in official documents.

<table>
<thead>
<tr>
<th>German name (translation)</th>
<th>noise reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lärmarmer Splittmastix Asphalt (low noise stone mastic asphalt), SMA\LA</td>
<td>???</td>
</tr>
<tr>
<td>Lärmoptimierte Asphaltdeckschicht (noise optimized asphalt surface), LOA</td>
<td>???</td>
</tr>
<tr>
<td>Dünne Asphaltdeckschicht im Heißeinbau auf Versiegelung (thin asphalt surface hot build on a sealing), DSH–V</td>
<td>???</td>
</tr>
<tr>
<td>Dünne Asphaltdeckschicht in Kaltbauweise (thin asphalt surface cold build), DSK</td>
<td>???</td>
</tr>
<tr>
<td>Porous Mastic Asphalt, PMA</td>
<td>???</td>
</tr>
<tr>
<td>Beton mit Grinding (cement concrete with grinding)</td>
<td>???</td>
</tr>
</tbody>
</table>

In the lower part of Table 2, there are two additional LNRs listed, which have so far no official reduction level and which are not mentioned in official documents.

There are also first attempts to describe urban low noise roads paved with cement concrete blocks.

3. SOUND MEASUREMENT DEVICES

3.1 Statistical Pass–By Method

To receive the noise emission of a road section, several methods are available. Beside the here described direct methods of noise measurements, the estimation of texture (and flow resistivity or acoustic absorption for porous surfaces) are sometimes leading to good results, when using them as input for a simulation model (2).

The Statistical Pass–By Method, SPB is described in ISO 11819–1:1997 (3). The maximum sound level of a big amount of vehicles passing by a microphone is measured. In the norm the horizontal distance from the middle axis of the vehicle to the microphone is 7.5 m and the height above the road surface is 1.2 m. In our institute we use microphones also at heights of 2.4 m, 3.6 m and 4.8 m. This is because of the situation at German motorways, where most of them are accompanied with guardrails or low walls of cement concrete, shielding the lower two microphone positions of 1.2 m and 2.4 m.
Together with the sound levels of the microphones, the speeds of the vehicles passing by are measured with an optical device from the side of the road (see Figure 1 left).

![Figure 1 – Standard SPB (left) and SPB with Array (right) at two different measurement sections (see Section 4.2).](image)

The meteorology (temperature of air and road surface, wind speed and direction) is measured at a height of 2.4 m beside the road. In the ISO standard the acoustical ambient conditions for the measurement location and the measurement conditions (meteorology, traffic flow) are described. But the measurement situations are not always ideal. The influence on the results of SPB–measurements is given e.g. in (4) and (5).

One point, which is not described, is the correction for temperature. If the air temperature deviates from 20°C a correction should be applied on the maximum sound levels measured. The higher the temperature the lower the noise emission of the tires. In Eq. (1) the temperature correction used in Germany is stated.

\[
L' = L + K_T \cdot (20°C - T_{air})
\]

with
- \(L'\) corrected maximum sound level in dB(A),
- \(L\) uncorrected maximum sound level in dB(A),
- \(K_T\) coefficient for temperature correction: 0.05 dB/°C and
- \(T_{air}\) air temperature in °C.

For measurements in different heights, a correction for the vertical directivity is applied to the maximum sound levels as well. In Eq. (2) the height correction is stated.

\[
L' = L + K_H \cdot \left(\frac{h}{d} - \frac{1.2}{7.5}\right)
\]

with
- \(L'\) corrected maximum sound level in dB(A),
- \(L\) uncorrected maximum sound level in dB(A),
- \(K_H\) coefficient for temperature correction: 5 dB,
- \(h\) height of microphone above the plane of the road surface and
- \(d\) horizontal distance from the middle axis of the vehicle to the microphone.

The correction for 3.6 m height of the microphone, used within this report, is 1.6 dB(A).

The amount of traffic on German roads is rising every year. Measurements with the normal SPB method is therefore often not possible. The method needs single vehicles, passing by the microphones with a reduction in noise level, before and after the vehicle is passing by, of at least 6 dB(A) and a constant gap to the surrounding noise of at least 10 dB(A). This could be reached on some motorway in the night time. But measurements at night are not as safe as with daylight. In (6) the influence of traffic on SPB–results is described.

Another method is using a linear microphone Array. Our institute is using an array existing of six microphones aligned horizontal with varied distances between them (see Figure 1 right). With this method
noise sources with a distance of only 10 m can be separated. Details of this method can be found (in German) in (7).

The Backing Board, BB, used for SPB in urban situations is described in ISO/PAS 11819–4:2013 (8) (see Figure 2).

The BB was developed further in the EU–project SILENCE. The idea is, to use a hard board as a backing surface of a microphone to shield disturbing noise. Because the geometry has changed from full space to half space an additional correction factor has to be used. The correction of BB is given by Eq. (3).

\[ L' = L + K_B \]  

with

- \( L' \) corrected maximum sound level in dB(A),
- \( L \) uncorrected maximum sound level in dB(A) and
- \( K_B \) coefficient for backing board correction: \( 20 \cdot \log(2) = 6 \text{ dB}(A) \).

This correction is valid for all vehicles (passenger cars, PCs, and heavy vehicles, HVs) passing by for the averaged A–weighted level. Only for lower and higher spectral frequencies, there are certain deviations from this formula (9). Up to now there is no correction used for this.

### 3.2 Close Proximity Method

Another method to get information about the noise emission of a LNR is the Close-Proximity method, CPX, after ISO/FDIS 11819–2:2016 (10). Normally two microphones in an absorbing chamber mounted on a trailer are towed by a vehicle (see Figure 3 left).

There are two tyres used in ISO/CD FDIS 11819–3:2016 (11) (see Figure 3 right). One tyre (left), an ASTM SRTT, has an average PC profile and the other (right), an Avon AV4 has a profile of a HV but with the same dimension as the other tyre. This is critical, specially for low frequencies, where the wavelength of the sound is even longer than the distance between footprint and microphone, which is about 30 cm. So the measurements are in the very near field of the tyre. This could lead to strong local gradients in the sound field.

Measurements with CPX have been conducted on some of the measurement sections but, the data available is not big enough to draw confident conclusions on them.

### 4. LNR DSH–V

#### 4.1 Description

Thin asphalt layers in hot construction are consisting of asphalt concrete for layers, AC D, stone mastic, SMA, or mastic asphalt, MA.
Thin asphalt surface hot build on sealing, DSH–V (Dünne Asphaltdeckschichten im Heißeinbau auf Versiegelung) consist of a bitumen, made with a polymer modified emulsion of bitumen, sealing the underlayment of the road and an immediately build special asphalt surface layer. The method is described in detail in the document ZTV BEA–StB 09 (12) as a regular road construction. The production is done by a road paver with integrated spray device. The spaying of the bituminous emulsion and laying of the asphalt surface is done in a single passage. The noise reduction of surfaces constructed with DSH–V is predominantly induced by the texture. Therefore choking after construction is not allowed.

4.2 Sections of Measurements

The LNR DSH–V was first used in 2005 on motorway in the south of Germany, especially in south Bavaria. But later some other Bundesländer of Germany made use of this surface type. In Table 3 selected measurement sections on German motorways are listed, showing interesting behaviour.

<table>
<thead>
<tr>
<th>No.</th>
<th>road</th>
<th>location</th>
<th>kilometrage</th>
<th>direction</th>
<th>year of construction</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A 952</td>
<td>Starnberg</td>
<td>2.400</td>
<td>west</td>
<td>2009</td>
</tr>
<tr>
<td>2</td>
<td>A 952</td>
<td>Starnberg</td>
<td>2.980</td>
<td>east</td>
<td>2009</td>
</tr>
<tr>
<td>3</td>
<td>A 44</td>
<td>Jülich</td>
<td>67.800</td>
<td>south</td>
<td>2012</td>
</tr>
<tr>
<td>4</td>
<td>A 45</td>
<td>Meinerzhagen</td>
<td>30.180</td>
<td>south</td>
<td>2012</td>
</tr>
<tr>
<td>5</td>
<td>A 99</td>
<td>AK München-Ost</td>
<td>38.980</td>
<td>south</td>
<td>2005</td>
</tr>
</tbody>
</table>

The rows of the Table are giving information for each section about road number, location, kilometrage, direction and year of construction. The year of construction is in the range of 2005 to 2009.

In Table 4 measurement sections on urban roads in Germany (Berlin) are listed.

<table>
<thead>
<tr>
<th>No.</th>
<th>location</th>
<th>road</th>
<th>direction</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Berlin–Reineckendorf</td>
<td>Karolinenstraße</td>
<td>north</td>
</tr>
<tr>
<td>7</td>
<td>Berlin–Reineckendorf</td>
<td>Zeltingerstraße</td>
<td>south–west</td>
</tr>
</tbody>
</table>

The construction year of these roads are not exactly know, but it should be around 2008 like the year of measurement.

On all measurement sections listed above, SPB measurements were performed. On section No. 5 also CPX measurements were conducted by an engineering consultant (Müller BBM).
5. RESULTS OF MEASUREMENTS

5.1 SPB–Results

The results of the SPB measurements on motorways are shown in Table 5.

Table 5 – SPB Measurements on motorways.

<table>
<thead>
<tr>
<th>No.</th>
<th>name</th>
<th>age</th>
<th>PC-level @120 km/h</th>
<th>HV-level @88 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>A_2011.10</td>
<td>2</td>
<td>79.0</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>A_2011.09</td>
<td>2</td>
<td>81.0</td>
<td>—</td>
</tr>
<tr>
<td>2</td>
<td>A_2015.15</td>
<td>6</td>
<td>81.8</td>
<td>—</td>
</tr>
<tr>
<td>3</td>
<td>A_2013.04</td>
<td>1</td>
<td>79.9</td>
<td>87.2</td>
</tr>
<tr>
<td>4</td>
<td>A_2013.03</td>
<td>1</td>
<td>84.0</td>
<td>88.3</td>
</tr>
<tr>
<td>5</td>
<td>A_2015.05</td>
<td>10</td>
<td>84.3</td>
<td>89.1</td>
</tr>
</tbody>
</table>

The rows of the Table are giving information for each section about the name used in the figures, the age when measured in years and the noise levels for passenger cars, PC, at 120 km/h and for heavy vehicles (on motorway those with more than 3 axes), HV, at 88 km/h. The speeds where chosen, because for normal dense traffic flow, these are the average speeds on motorways for PC and HV respectively.

The noise level for PCs at 120 km/h are in the range of 79.0 dB(A) to 84.3 dB(A). The German reference value for the reference surface of non grooved mastic asphalt is 85.2 dB(A). So the reduction of noise emission is in the range of 0.9 dB(A) to 6.2 dB(A). For HVs at 88 km/h the noise level is in the range of 87.1 dB(A) to 89.1 dB(A). A reference value for this speed can be calculated with new emission data for HVs as 91.9 dB(A). Here the reduction of noise emission is in the range of 2.8 dB(A) to 4.4 dB(A). It should be mentioned, that only on the heavy trafficked sections No. 3 to No. 6 the measurement of HVs were possible. On the other sections then traffic volume of HVs was to low (see Section 5.2).

As an example in Figure 4 measurement sets of sound pressure level versus logarithm of velocity are shown for PCs (left) and HVs (right) for the measurement site No. 5.

![Figure 4](image)

Figure 4 – Sound pressure level versus logarithmic velocity and fitting functions for SPB–levels at a microphone height of 3.6 m.

The fitting functions shown are the linear regression line and the hyperbolic lines for the deviation of the regression line by plus or minus one standard deviation.

The velocity of PCs is in the range of 100 km/h to about 130 km/h with only a few faster vehicles. The road section was a heavy trafficked motorway with three lanes per direction. For the HVs the speed range is from 80 km/h to 90 km/h. Therefore the reference speeds for PCs and HVs of 120 km/h and 88 km/h respectively are in the bulk of the distribution.
In Figure 5 a normalised frequency spectrum (left) and a spectrogram (right) are shown for PCs at section No. 1. 

(a) Spectrum. 

(b) Spectrogram. 

Figure 5 – Spectrum and spectrogram. 

The normalisation of the spectrum leads to negative third octave levels, which summed are 0 dB(A). In the figures the velocity is in the range of 100 km/h and 130 km/h. The frequency range is for the third octave spectrum from 500 Hz to 5 kHz and for the third octave spectrogram from 100 Hz to 5 kHz. 

This section has the lowest noise emission level measures with SPB for PCs. The speed dependency of the spectra is quiet different for different spectral ranges. At the frequencies of about 700 Hz, 1250 Hz and from 2 kHz to 2.5 kHz the normalized sound pressure levels are almost identical for all speeds. For lowest speeds of 100 km/h there is a main peak at 1 KHz and a weak side peak at 2 KHz. At 1.6 kHz a recess in the curve is visible. At higher speeds this recess disappears and the maximum peak is moving to 1250 Hz at 130 km/h. This can be seen also in the spectrogram.

In Figure 6 the spectra for PCs at section No. 2 with an age of 2 years (left) and 6 years (right) are shown.

(a) 2 years old. 

(b) 6 years old. 

Figure 6 – Spectra for PCs at section No. 2. 

In principle the normalized spectra at section No. 2 are like the ones at section No. 1. But the recess at 1.6 kHz at low speed at 100 km/h is not as pronounced, even less for the 6 years old NRA compared to the 2 years old one. For high speed at 130 km/h a further peak shift towards 2 kHz can be recognized.
The spectra for PCs are comparable with those in section No. 2, which are on 2 years old surfaces. But also for low speeds at 100 km/h a peak shift to 1250 Hz is visible. For HVs the normalized sound pressure levels are almost identical for all speed at the frequencies of about 600 Hz, 800 Hz, 1250 Hz and 2 kHz. There is a main peak at 800 Hz and weak peak at 1600 Hz with an recess at 1250 Hz.

In Figure 8 the spectra for PCs (left) and HVs (right) at section No. 4 are shown.

The spectra for PCs are comparable with those in section No. 1. For HVs the peak at 800 Hz is more pronounced than in section No. 3.
In Figure 9 the spectra for PCs (left) and HVs (right) at section No. 5 are shown.

Figure 9 – Spectra at section No. 5.

The spectra for PCs and HVs do nearly have no speed dependency. The peak at 1 kHz and 800 Hz respectively are very pronounced.

The results of the SPB measurements on urban roads are shown in Table 6.

Table 6 – SPB Measurements on urban roads.

<table>
<thead>
<tr>
<th>No.</th>
<th>road</th>
<th>PC-level @50 km/h</th>
</tr>
</thead>
<tbody>
<tr>
<td>6</td>
<td>Karolinenstraße</td>
<td>68.4</td>
</tr>
<tr>
<td>7</td>
<td>Zeltingerstraße</td>
<td>67.6</td>
</tr>
</tbody>
</table>

The noise level for PCs at 50 km/h are in the range of 67.6 dB(A) to 67.6 dB(A). The German reference value for the reference surface of non grooved mastic asphalt at 50 km/h is 73.6 dB(A). So the reduction of noise emission is in the range of 5.2 dB(A) to 6.0 dB(A) like for motorway in new condition.

5.2 Traffic Volume

The traffic volume for the measurement sections on motorways are derived from a website of the BASt (13) and listed in Table 7.

Table 7 – Traffic volume on measured motorways.

<table>
<thead>
<tr>
<th>Nr.</th>
<th>age years</th>
<th>AADT veh./24h</th>
<th>AADT of HVs veh./24h</th>
<th>part of HVs</th>
<th>total HVs mio. veh.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>14,049</td>
<td>383</td>
<td>3%</td>
<td>0.3</td>
</tr>
<tr>
<td>2</td>
<td>2</td>
<td>14,769</td>
<td>398</td>
<td>3%</td>
<td>0.3</td>
</tr>
<tr>
<td>2</td>
<td>6</td>
<td>14,512</td>
<td>402</td>
<td>3%</td>
<td>0.9</td>
</tr>
<tr>
<td>3</td>
<td>1</td>
<td>17,134</td>
<td>1,986</td>
<td>12%</td>
<td>0.7</td>
</tr>
<tr>
<td>4</td>
<td>1</td>
<td>32,296</td>
<td>6,313</td>
<td>20%</td>
<td>2.3</td>
</tr>
<tr>
<td>5</td>
<td>10</td>
<td>52,901</td>
<td>6,208</td>
<td>12%</td>
<td>22.7</td>
</tr>
</tbody>
</table>
The rows of the Table are giving information for the sections and ages about the averaged annual daily traffic, AADT the AADT of HVs, the part of HVs and the total HVs.

The AADTs of the first 3 sections are almost the same. The AADTs of section No. 4 and No. 5 are double and three times as high. But the AADTs of HVs are quite different. For the first sections the part of HVs is 3%. Section No. 3 and No. 5 are having 12% and section No. 4 has 20% part of HVs. The total amount of HVs is the same and with 0.3 mio. vehicles very low for section No. 1 and section No. 2 after 2 years. For section No. 2 after 6 years and section No. 3 after 1 year the amount of HVs is 0.9 mio. vehicles and 0.7 mio. vehicles respectively. Sections No. 4 and specially No. 5 are having a big amount of HVs with 2.3 mio. vehicles and 22.7 mio. vehicles respectively. These figures were used for further analysis in Section 5.3.

5.3 Time Series

In Figure 10 the SPB–level of PCs at 120 km/h is shown as a function depending on age (left) and depending of load (total AADT of HVs) for measurement sections on motorways.

![Figure 10](image)

(a) Time dependency.  
(b) Heavy traffic dependency.

Figure 10 – SPB–level for PCs at 120 km/h as a function of age and amount of AADT of HVs.

The red spots are the results from the measurement sections (see Section 5.1). The blue spots are further measurements on other motorways. The thick lines are the logarithmic regression lines, the thin lines are the up and down shifted logarithmic regression lines in a way, that approximately a quarter of the 16 points are lying above or below these lines.

The coefficient of determination $R^2$ for the logarithmic regression with age is only 0.11, while it has an value of 0.62 for the logarithmic regression with total AADT of HVs.

The formula for the regression with age is

$$L_{SPB} (t) = 80.9 + 1.27 \cdot \lg (t)$$  \hspace{1cm} (4)

with

- $L_{SPB}$ estimated SPB–level corrected maximum sound level in dB(A) and
- $t$ age of the surface in years.

Here the regression lines are shifted by ±1 dB(A).

The formula for the regression with total AADT of HVs is

$$L_{SPB} (W) = 81.1 + 1.96 \cdot \lg (W)$$  \hspace{1cm} (5)

with

- $L_{SPB}$ estimated SPB–level corrected maximum sound level in dB(A) and
- $W$ load: total AADT of HVs.

Here the regression lines are shifted by ±0.5 dB(A).
6. CONCLUSIONS

The result in Section 5.1 are leading to the conclusion, that in principle there is not only an increase of noise emission levels of LNRs made of DSH–V with time but also a change in the spectra for different speeds. For the noise emission of PCs on new surfaces there is a recess at about 1.6 kHz for low speeds. This recess vanishes with higher speeds or with the age of the surface. The conclusion is, that initially there is an effect from the texture of the road surface leading to this recess. It could be acoustic absorption but more reasonable it is an effect of avoiding air–pumping. This would be in line with the findings of the Project QUESTIM (14), that clogging of the top layer increases the flow resistivity and is leading to the observed changes in spectra.

The second conclusion is, that the speed dependency of the spectra is reducing with the age of the surface. In the end the spectra for the different driving speeds are almost the same. This is valid for PCs and for HVs as well. It would be very appreciated, when more measurements of textur and airflow resistivity could be conducted at those surfaces.

When looking at the dependency of the noise emission level with time or load, a logarithmic regression can used to describe the behaviour. The regression with time is much more unconfident than the one with load. After 10 years the noise emission level for PCs is predicted with 82.2 dB(A) while for heavy trafficked roads (AADT of 50,000 with 12% of HVs) the prediction noise level with 83.7 dB(A) is substantially higher when using the dependency with load.

LNRs made of DSH–V initially are having a high noise reduction. They can be used on motorway with low traffic volume. When the traffic volume is too high, the exposure time should be limited by the total AADT of HVs rolling on the surface in this time span. For urban roads the noise reduction is at about 5 dB(A) to 6 dB(A) as on motorways for the initial good condition of the surface. For motorways the initial noise reduction is in the range of 4 dB(A).

REFERENCES


