Hybrid passive-active absorption of broadband noise using MPPs

P. Cobo, A. Fernández
Instituto de Acústica. CSIC. Serrano 144, 28006 Madrid, SPAIN

Passive materials provide sound absorption in a frequency band whose low frequency limit depends on its thickness. In general, sound absorption in the lower frequency range requires such bulky materials that the passive solution becomes impractical, except for special installations, such as anechoic chambers. On the other hand, active systems allow control of the input impedance of multilayer absorbers, affording low frequency absorption. When the properties of the passive system are properly combined with the active controller, it is possible to design broadband sound absorbers with an absorption coefficient close to unity from 100 Hz. These systems are named hybrid passive-active absorbers. This paper describes the implementation of such a hybrid absorber, using a microperforated panel (MPP) as the passive material.

1. INTRODUCTION

The weight and/or size requirements for passive absorption at low frequencies are often excessive. The more recent technology of active noise control can be used effectively at low frequencies. Thus, it is useful to consider hybrid systems that combine passive and active techniques to provide absorption at both low and high frequencies.

Passive absorption is often afforded by a system consisting of an air cavity between a porous or fibrous layer and a rigid wall. Depending on the properties of the porous layer and the thickness of the porous and air layers, such a two-layer system is capable of providing high absorption at medium and high frequencies, with maxima at those frequencies for which the air layer thickness is an odd-integer multiple of the quarter-wavelength. An active equivalent of this *l/4 resonance absorber* is obtained by replacing the rigid wall with a loudspeaker driven such that zero sound pressure is achieved at a microphone positioned on the rear face of the porous layer. Furtoss et al. (1997) named this strategy the *pressure release* condition.

Beyene and Burdisso (1997) proposed canceling the reflected component of the standing wave in the air layer to further increase the active absorption of the hybrid passive-active system (the *impedance matching* condition). The accomplishment of such a condition required two closely spaced microphones together with a deconvolution circuit, to separate both the incident and reflected plane waves in the air cavity. Using such a hybrid passive-active system, they reported a high absorption coefficient in the range of 0.8-1.0 in the 100-2000 Hz frequency band. Cobo et al. (2003) carried out a theoretical and experimental comparison of both conditions (pressure release and impedance matching) concluding that the pressure release condition is capable of providing higher values of absorption than the impedance matching condition when the flow resistance of the porous layer equals the acoustic impedance of air.

The total thickness of the hybrid system can be further decreased by using microperforated panels (MPP) as the absorbent material (Cobo *et al.*, 2004). A MPP consists of a thin sheet panel perforated with many orifices of submillimeter size distributed along its surface (Maa, 1998). This absorber has remarkable practical benefits since it is lightweight and, with an appropriate material selection, can be inexpensive. It also produces less health-related concerns than fibrous materials.

The main objective of this paper is to analyze the potential of a hybrid passive-active system to provide wideband absorption using MPP as the passive absorbent. Preliminary experiments with such a system showed promising results (Cobo *et al.*, 2004). A model of propagating plane waves in a tube allows the absorption coefficient to be evaluated using the pressure release condition. In Section 2 the equations of the microperforated panels (MPP) are reviewed (Maa, 1998; Pfretzschner *et al.*, 2006)). The control by pressure release condition of a hybrid system using a MPP, is analyzed in Section 3. The description of the experimental setup and the experimental results are given in Section 4.

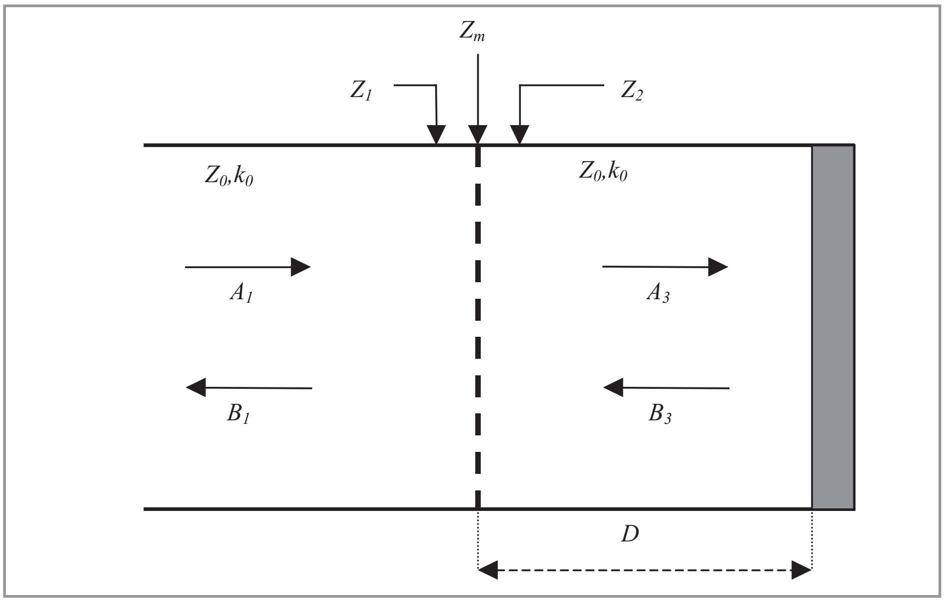

Figure 1. Scheme of the passive MPP absorber

2. MICROPERFORATED PANELS

Let us consider the sound absorbing system sketched in Figure 1. It consists of a MPP, of acoustic impedance Z_m, in front of an impervious wall, with an air cavity of depth D in between. Let Z_0 be the air acoustic impedance, and Z_1 and Z_2 the acoustic impedances at left and right sides of the MPP, respectively. The plane wave absorption coefficient at normal incidence of this system is

$$\alpha(f)=1-|R(f)|^2, \tag{1}$$

where

$$R(f)=\frac{Z_1(f)-Z_0}{Z_1(f)+Z_0}. \tag{2}$$

The acoustic impedance at the left side of the MPP is

$$Z_1 = Z_m + Z_2, \tag{3}$$

where Z_2, the acoustic impedance of the air cavity is

$$Z_2 = -jZ_0 \cot(kD), \tag{4}$$

being $k = \omega/c$ the wave number.

The acoustic impedance of the MPP is required to complete the model. Pfretzschner et al. (2006) combine a thick, macroperforated panel with a thin, microperforated mesh to provide an MPP with more manageable mechanical properties. They named this absorbing system a microperforated insertion unit (MIU). The acoustical impedance of such a MIU is

$$Z_m = j\frac{\omega\rho t_1}{p_1}\left[1-\frac{2\ J_1(x_1\sqrt{-j})}{x_1\sqrt{-j}\ J_0(x_1\sqrt{-j})}\right]^{-1}+\frac{\sqrt{2}\eta x_1}{p_1 d_1}+j\frac{0.85\omega\rho d_1}{p_1}$$
$$+j\frac{\omega\rho t_2}{p_2}\left[1-\frac{2\ J_1(x_2\sqrt{-j})}{x_2\sqrt{-j}\ J_0(x_2\sqrt{-j})}\right]^{-1}+\frac{\sqrt{2}\eta x_2}{p_2 d_2}+j\frac{0.85\omega\rho d_2}{p_2}, \quad (5)$$

where (d_1,t_1,p_1) are the hole diameter, thickness and perforation ratio of the thick panel, (d_2,t_2,p_2) are the hole diameter, thickness and perforation ratio of the thin mesh, J_0 and J_1 are Bessel functions of the first kind and orders zero and one, respectively, *h* and *r* are the air viscosity coefficient and density, respectively, *h* and

$$x_1 = \frac{d_1}{\sqrt{\frac{4\eta}{\rho\omega}}}, x_2 = \frac{d_2}{\sqrt{\frac{4\eta}{\rho\omega}}}. \quad (6)$$

Equations (1)-(6) allow calculation of the absorption coefficient of the MIU as a function of the acoustic parameter *f*, the MIU parameters (d_1, t_1 ,p_1, d_2, t_2 ,p_2), and the cavity parameter *D*. Habitually, the MIU is built covering the holes of the thick panel with a micrometric mesh of d_2, t_2 and p_2 fixed. Therefore, assuming t_1 also fixed, the absorption coefficient depends on the frequency, *f*, the thickness of the air cavity, *D*, and the d_1 and p_1 parameters. As is well known, increasing *D* moves the absorption curve towards the low frequency range. In the following *D* will be set to 5 cm. Figure 2 shows the absorption coefficient as a function of (*f*, p_1) with (d_1,t_1,d_2,t_2,p_2,*D*)=(6 mm,1 mm,39 mm,35 mm,14 %,5 cm). As can be observed, the maximum absorption is obtained for p_1=23 %. Figure 3 shows the absorption coefficient as a function of (*f*, d_1) with (t_1,p_1,d_2,t_2,p_2,*D*)=(1 mm,23 %,39 mm,35 mm,14 %,5 cm). In this case, the absorption curve narrows and moves towards lower frequencies when the hole diameter of the thick panel increases.

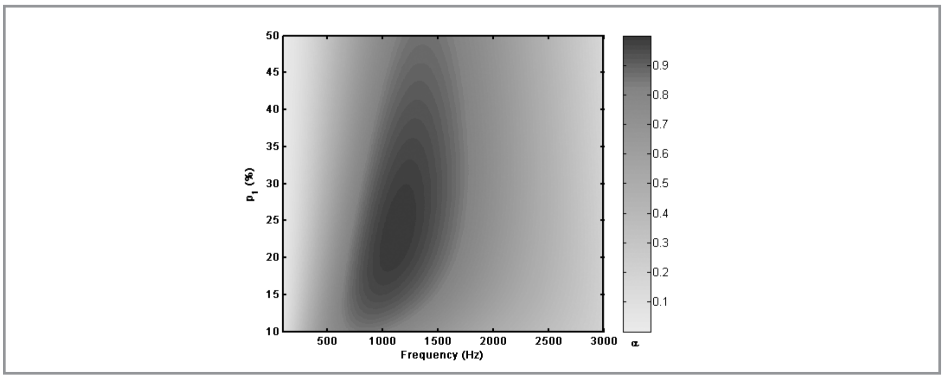

Figure 2. Passive absorption chart of a MIU as a function of (f, p_1) with parameters (d_1, t_1, d_2, t_2, p_2, D) = (6 mm, 1 mm, 39 mm, 35mm, 14 %, 5 cm).

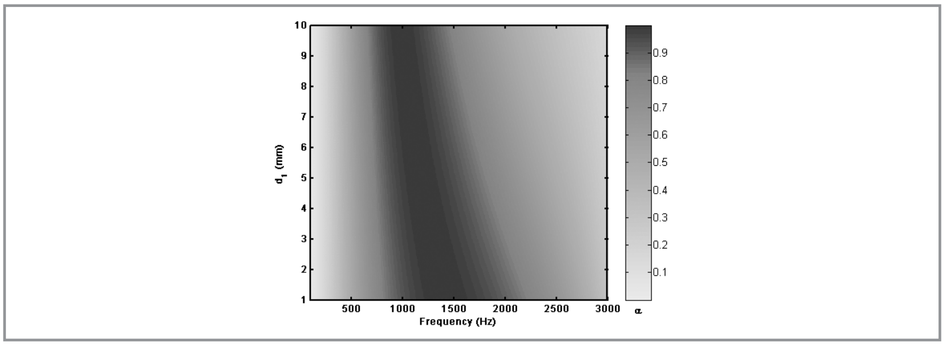

Figure 3. Passive absorption chart of a MIU as a function of (f, d_1) with parameters (t_1, p_1, d_2, t_2, p_2, D) = (1 mm, 23 %, 39 mm, 35mm, 14 %, 5 cm).

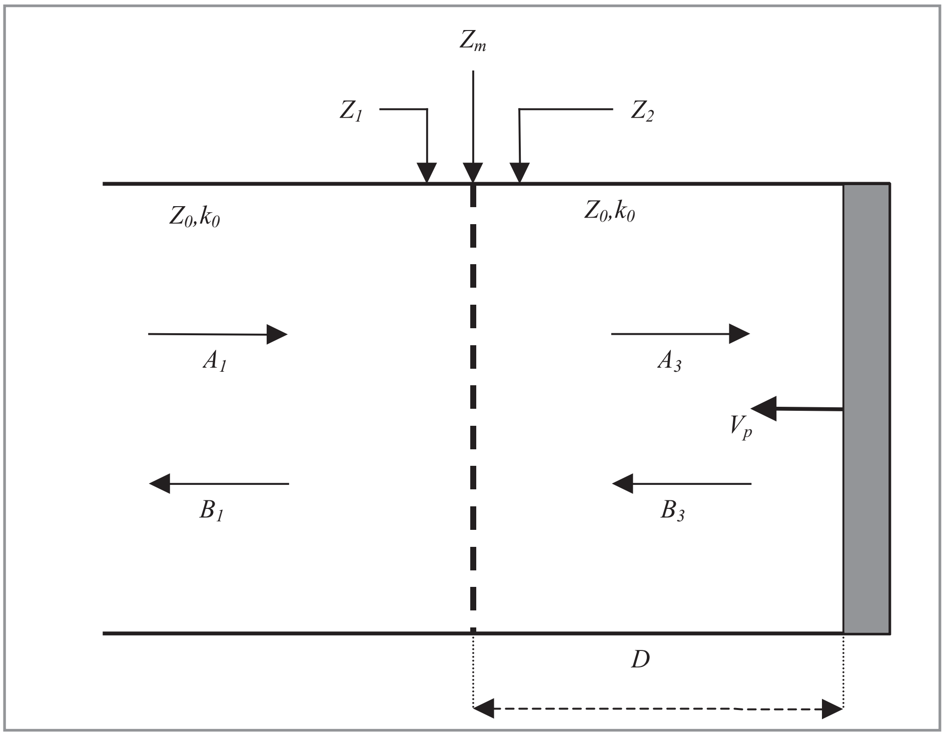

Figure 4. Scheme of the hybrid passive-active absorber, using a MPP and a piston for the passive and active parts, respectively

3. HYBRID PASSIVE-ACTIVE ABSORPTION

Figure 4 shows the scheme of a hybrid passive-active system using a MPP as the passive absorbent. The active component of the hybrid system is a piston instead of the back wall moving forward and backward with velocity V_p.

The specific acoustic impedance at the cavity side of the MPP becomes in this case (Cobo et al., 2004)

$$Z_2 = Z_0 \frac{Z_0 V_p + 2B_2 \cos(kD)}{Z_0 V_p + 2jB_2 \sin(kD)} . \tag{7}$$

Using Eq. (7) the following control conditions can be examined:

- In the passive case, $V_p = 0$ and Z_2 in Eq. (7) becomes equal to Z_2 in Eq. (4).
- In the active case, using the pressure-release condition, $P_2 = 0$, and Z_2=0.

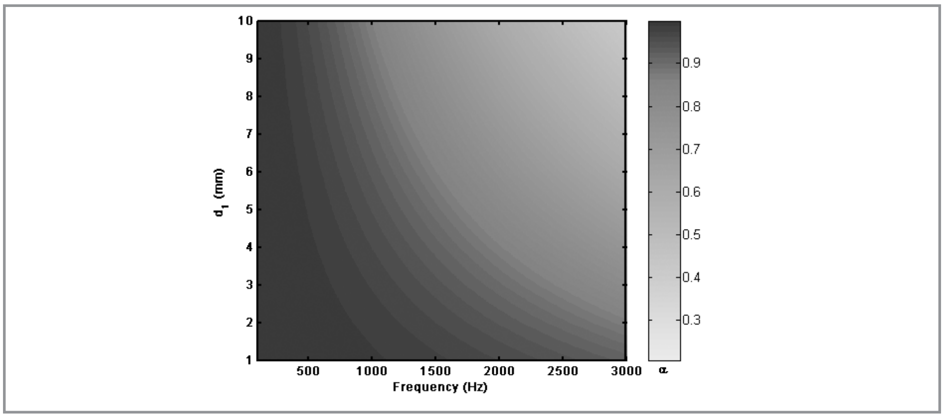

Figure 5. Active absorption chart of a MIU as a function of (f, d_1) with parameters (t_1, p_1, d_2, t_2, p_2, D) = (1 mm, 23 %, 39 mm, 35mm, 14 %, 5 cm).

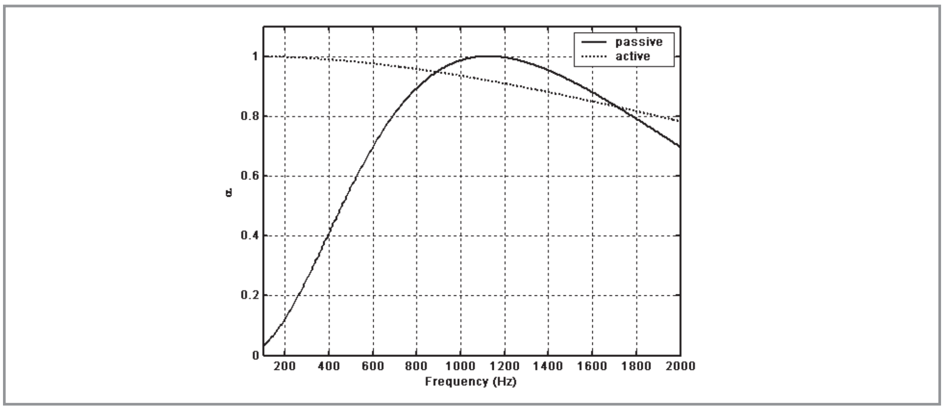

Figure 6. Passive and active absorption curves of a MIU with parameters (d_1, t_1, p_1, d_2, t_2, p_2, D) = (6 mm, 1 mm, 23 %, 39 mm, 35mm, 14 %, 5 cm).

Figure 5 shows the active absorption coefficient as a function of (f, d_1), under the pressure release condition, of a MIU with (t_1, p_1, d_2, t_2, p_2, D) = (1 mm, 23 %, 39 mm, 35mm, 14 %, 5 cm).

As can be seen in Figure 5, active control provides absorption at low frequencies. Also, the smaller the holes of the thick panel, the wider the active absorption curve.

Figure 6 shows the passive and active absorption curves of a MIU for (d_1, t_1, p_1, d_2, t_2, p_2, D) = (6 mm, 1 mm, 23 %, 39 mm, 35mm, 14 %, 5 cm). The active system should be able to provide values of absorption close to 100 % at frequencies below 900 Hz. However, the passive MIU outperforms the active between 900 and 1700 Hz. Thus, active control is deleterious in this frequency band. Bearing in mind that active control does not perform at high frequency, hybrid passive-active absorption is obtained when the active controller is low-pass filtered at 900 Hz.

4. EXPERIMENTAL RESULTS

An experimental hybrid passive-active system with a MIU as the passive absorber was implemented. Figure 7 shows the MIU with parameters (d_1, t_1, p_1, d_2, t_2, p_2, D) = (6 mm, 1 mm, 23 %, 39 mm, 35 mm, 14 %, 5 cm).

All absorption measurements were carried out in a standard impedance tube with the same setup described by Cobo *et al*. (2003). The primary broadband noise was generated by a loudspeaker located at one end of the tube. The MIU absorber was placed at the other end. The active system consisted of a secondary loudspeaker with flat diaphragm, an error sensor (a 1/4 inch microphone) located just behind the MIU, and a digital controller. The absorption coefficient was measured by means of the transfer function method (Chung and Blaser, 1980) using two microphones upstream to the tube, separated by 18 cm. The dimensions of the tube (10 cm diameter and 1 m length) and the separation of the two measurement microphones limit the valid frequency measurement bandwidth from 190 Hz to 1715 Hz (ISO 10534-2). Figure 8 shows the measured passive, active, and hybrid passive-active absorption curves for this MIU. The hybrid system yields an average absorption of 94 % in the frequency band from 190 to 1715 Hz.

Figure 7. A MIU with parameters (d1, t1, p1, d2, t2, p2, D) = (6 mm, 1 mm, 23 %, 39 mm, 35 mm, 14 %, 5 cm).

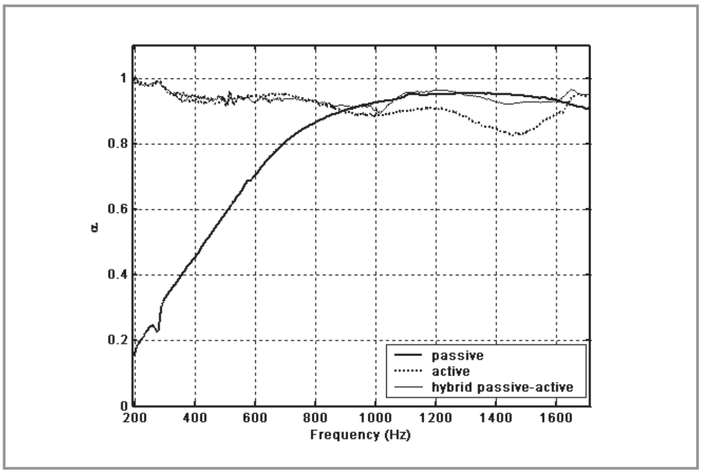

Figure 8. Absorption curves of the MIU shown in Figure 7

5. CONCLUSIONS

This paper has reported the feasibility of a hybrid passive-active absorber to provide good broadband sound absorption. In this system, a MIU was used in place of conventional fibrous materials as the passive absorber. The active controller releases the pressure in the interior of the air cavity, which yields absorption in front of the MIU. Even though the actively controlled system achieves high values of absorption across the frequency range considered, a better solution is provided using only the passive element when it alone affords better absorption. Thus, a hybrid solution is suggested, low-pass filtering the error signal of the control system.

The designed hybrid absorber has a total thickness of 5 cm and provides an average absorption coefficient of 0.94 in the frequency band from 190 to 1715 Hz.

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CHANGE ENTAILS MORE CHANGE

New measures to curb excessive noise pollution from pubs and clubs could be implemented following consultation, as the final part of the Clean Neighbourhoods and Environment Act comes into force. Defra is seeking views on the draft guidance for the measures, which will be designed to combat noise problems arising from the longer hours allowed by the recently changed licensing laws. The existing noise regulations (Noise Act 1996) can only be used to deal with night-time noise from residential buildings. Offenders under the proposed legislation could be liable to on-the-spot fines of up to £500, or maximum fines of £5000 if the case is taken through court. "In the past, excessive noise from pubs and clubs had to be ongoing for any offence to take place. That doesn't help those who have had their sleep disturbed into the early hours on the odd occasion - especially given the longer opening hours we have now," said Local Environment Minister, Ben Bradshaw. "With the new powers, local authorities can deal with one-off incidents of excessive noise from licensed premises.

DISPUTE OVER NOISE LED TO SHOOTING

An ongoing dispute over working too loudly on vehicles in an apartment complex parking lot led to a man being shot to death, police said. Police found the 45-year-old shooting victim about 7 p.m 22 June in the doorway of an apartment in the 3500 block of East Second Street, near East Speedway and North Palo Verde Avenue, Tucson police said. Homicide detectives learned that the victim and a 57-year-old man who both lived at the complex were fighting because the victim was being too noisy while working on vehicles,said Sgt. Decio Hopffer, a department spokesman.

SCHENECTADY ORDINANCE

The Schenectady City Council passed a beefed-up noise ordinance at the end of June, a change that comes as city officials consider ways to crack down on a Northside inn that hosts swingers parties. Union Street Bed & Breakfast owner Bob Alexson said the move had no bearing on his business. One person, he said, made all eight noise complaints over a one-year period. Alexson said he doesn't even allow music. "There's never been any noise here," Alexson said after the meeting, which he watched on television at the inn. "Everybody knows it. We all laugh about it." Alexson, a self-described swinger, lives in the bed and breakfast and contends the parties are part of his private life, off-limits to government regulation.

CALGARY ROAD CREWS

City of Calgary noise bylaws do not apply to road crews doing work on Deerfoot Trail in the middle of the night. Some southeast Calgary residents complain that re-surfacing of nearby Deerfoot is very noisy, and continues until at at least midnight. But City of Calgary Bylaw manager Bill Bruce says he doesn't have any say over that. He says Deerfoot is a provincial roadway, so municipal bylaws don't apply when it comes to the roadway itself. He also says provincial road crews are exempt from noise bylaws. He says City of Calgary road crews are also exempt from noise bylaws, but he points out they do warn people ahead of time about the work, why it's needed, and how long it will take.

TRAIN WHISTLES IN EUGENE

With more than 20 trains rumbling through Eugene, Oregon, day and night, locomotive whistles are a familiar part of the city's soundscape. But at the request of sleep-deprived residents who live near railroad tracks, the City Council has decided that it wants to explore the possibility of making the city a little quieter. Councillors directed city engineers to study the pros and cons of closing up to four downtown area railroad crossings along with other changes so train drivers wouldn't have to sound their whistles as they approach the crossings. New federal regulations allow cities to make safety improvements at railroad crossings to establish so-called quiet zones. Train drivers can still sound their horns if they see a potential hazard on or near railroad tracks.

SUBSIDIARITY WITHOUT FUNDING

Cracking down on neighbourhood noisemakers has become a local law enforcement issue since a budget cut gutted the Maryland Department of the Environment's noise-control programme last year, county governments are learning. A state law limiting noise in residential neighbourhoods to 65 decibels in the daytime and 55 decibels at night remains in effect, but it can be enforced only by designees of the state secretary of the environment, MDE spokesman Charles Gates said. Since the General Assembly eliminated the programme's funding in 2005 to save $50,000- the cost of wages and benefits for the lone inspector - noise pollution has became a local problem. "We have begun encouraging local municipalities and counties to consider implementing their own noise-pollution laws," Gates said. This process is mirrored in other states.

POLICE ACT!

Police officers have seized hi-fis, speakers and CD players from a house in Bath in an attempt to end a long-running noise row. Neighbours have been complaining about excessively loud music coming from the house in Whiteway, for more than six months. But despite a noise abatement notice being served, the music had continued. Now police and council workers have executed a seizure warrant and removed the stereo equipment. Sgt Michael Sherborne said: "We have received a number of complaints from residents who were having their quality of life severely disrupted by nuisance noise. This positive action shows that we will do all we can to address peoples' concerns."