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On the power and frequency of auditory signals on emergency vehicles

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ABSTRACT
Sirens from emergency vehicles are particularly annoying for people living in the vicinities of hospitals. The power regulations for sirens vary for different countries as well as it does their frequency content. In order to reduce their annoyance the present work computes the optimal output power and frequencies of the siren by taking into account the car's sound insulation, the background noise inside the car and the masked threshold of hearing. The combination of these parameters gives rise to frequency windows where the sirens are more effective, so new tones are proposed and their annoyance is assessed through a jury test procedure.
Keywords: Auditory Signals, Emergency Vehicles, Sirens

1. INTRODUCTION

Acoustic sirens from emergency vehicles are an annoying part of the soundscape in cities, especially those from fire brigades and ambulances since they tend to be clustered around fire departments and hospitals bothering the same population on a regular basis.

Although there exist local regulations about the minimum and maximum power for sirens it is not known whether these levels are adequate or not. As for the frequency content of sirens, it does not exist any regulation at all.

The objective of this study is to define new tones for sirens and their required output power to produce less annoyance while keeping the detectability of the current tones. We have not investigated new signals but variations of the classic tones: Wail, Yelp, Two-Tones and Three-Tones.

The article is structured as follows: in the following section it is described the procedure used to compute the optimum power and frequencies for sirens, afterwards the results are presented and discussed, and finally the proposed new tones are evaluated by means of a jury test.

2. PROCEDURE

The acoustic power and frequency of a siren must be that which grants that the drivers in front of the emergency vehicle perceive it with enough time as to clear its path without perturbing it.

The problem of the detection of a siren by a driver is equivalent to the problem of detecting a pure tone masked by broadband noise with the pure tone being attenuated not only due to the distance to the source but also by the insulation of a cabin. So in order to define the proper acoustic power for a siren to be heard from inside a car it is necessary to measure the car's insulation and its interior noise. The car's insulation decreases the sound pressure level (SPL) of the siren inside the receiver vehicle. In addition, the interior noise in the receiver car raises the driver's hearing threshold in quiet because it masks the siren noise.

Sound insulation and interior background noise have been measured (Sections 3.1 and 3.2) for ten different cars of different categories and ages: Alfa Romeo GT (2005), Audi A4 (2008), Chrysler Voyager (1996), Citroen C2 (2008), Fiat Punto (1999), Ford Cmax (2007), Ford Fiesta (2004), Ford

Focus (1999), Opel Astra (2005) and Seat Ibiza (1997).

Since the siren must be clearly audible, its level must be well above the hearing threshold, which represents a 50% detection probability. Several studies indicate that for a signal to be clearly detected its level must be 12 dB to 15 dB above the hearing threshold [6, 5, 4]. The criterion followed in this work is that the siren will be clearly detected if, inside the receiver car, its level is 15 dB above the masked threshold for at least one one-third octave band.

3. RESULTS

3.1 Car Sound Insulation

The sound insulation measurements have been carried out following the norm ISO 11957:1996 "Acoustics -- Determination of sound insulation performance of cabins -- Laboratory and in situ measurements" [2].

The sound insulation, D_p, is the difference between the SPL outside and inside the car:

$$D_p = L_{p_{ext}} - L_{p_{int}} \tag{1}$$

Figure 1 shows the insulation levels in one-third octave bands from 100 Hz to 10000 Hz for four of the ten cars measured. As a conclusion, all cars have three drops in insulation, one between 200 Hz and 500 Hz, another between 1000 Hz and 1250 Hz and a third one around 4000 Hz.

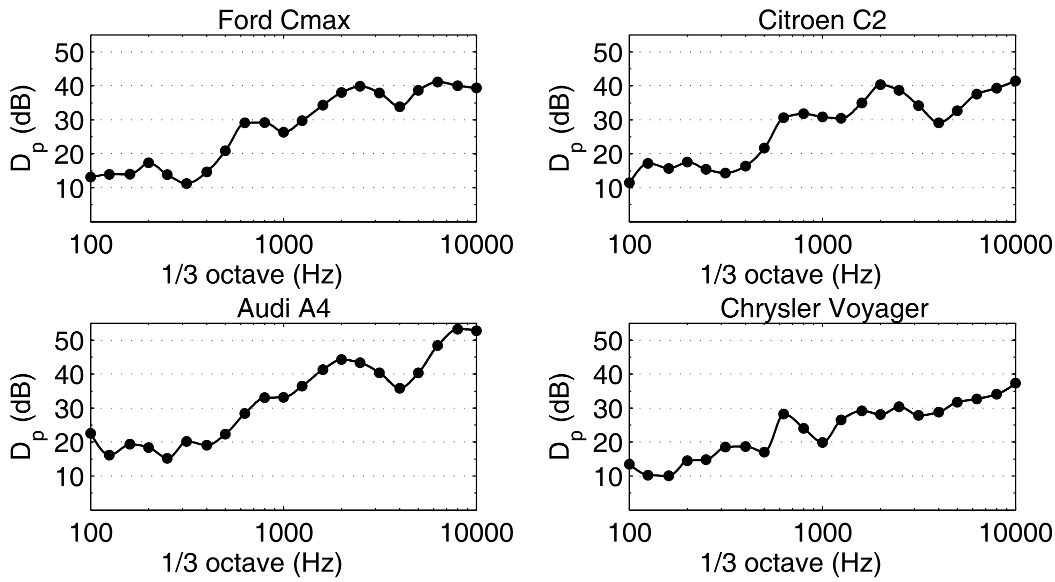

Figure 1: Car insulations in one-third octave bands.

3.2 Inside Background Noise

The inside background noise in urban driving has been measured also for each car. A sound meter situated at the front passenger's head measured the SPL in one-third octave bands every 125 ms during a ten minute urban drive without speaking and with radio off. Figure 2 shows one-third octave band spectra of the inside background noise for four of the ten cars measured. The typical spectrum is dominated by low frequencies, it falls down about 10 dB from 100 Hz to 400 Hz, and then it reaches a plateau up to a 1000 Hz and rapidly falls down again at higher frequencies.

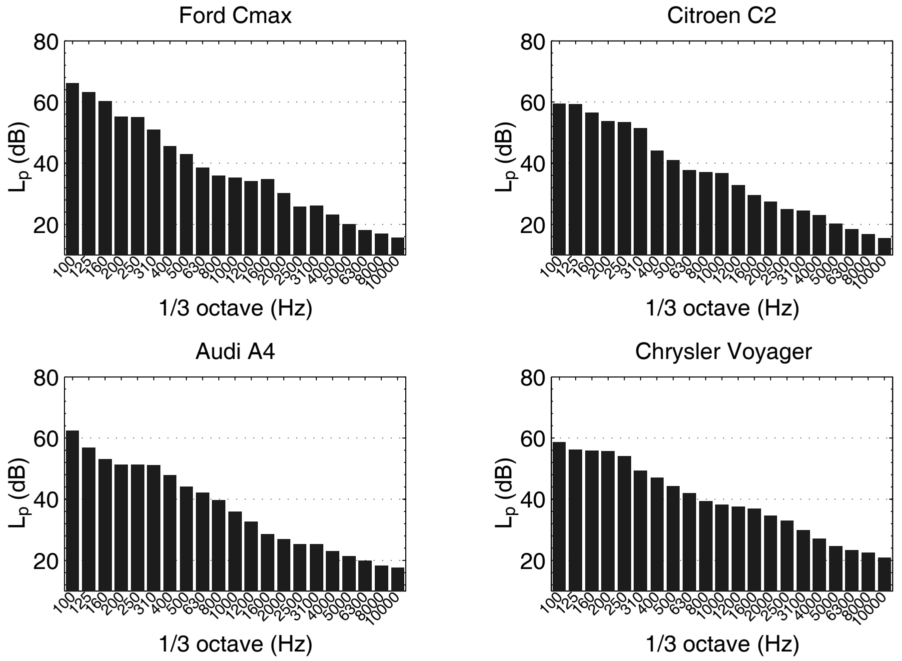

Figure 2: Inside background noise in urban driving regime.

3.3 The Masked Threshold

The presence of a background noise reduces the ability of the ear to discern other sounds. The hearing threshold in the presence of a background noise is then elevated because of the masking noise.

Following [3], in the presence of a broadband background noise the elevation of threshold in dB for a sinusoidal signal can be calculated from:

$$SPL_{background} + 10 log_{10} \frac{f_0 \pi^2}{Q(f_H - f_L)} \tag{2}$$

where Q is the figure of merit for the ear considered as a filter (as tabulated in [3]), f_0 is the central frequency of the one-third octave band and ($f_H - f_L$) is its bandwidth.

The masked threshold is calculated with Equation 2 plus the hearing threshold in quiet. The hearing threshold used in this work is the corresponding to a 60 years old male.

3.4 Siren Requirements

In order to determine the required output power for a siren, the present work assumes that the distance from which it has to be detected is 60 m.

The masked threshold plus 15 dB plus the car insulation propagated to a distance of 57 m gives the SPL at 3 m that should have a siren at a given one-third octave band to be clearly detectable inside a given car. This SPL is plotted in Figure 3 for four of the ten cars measured.

Figure 3 shows three windows of opportunity around 400 Hz, 1000 Hz and 4000 Hz.

The 4000 Hz window is not convenient to use because of the higher air and asphalt absorption at high frequencies [1] and the increase of the hearing threshold at high frequencies with age.

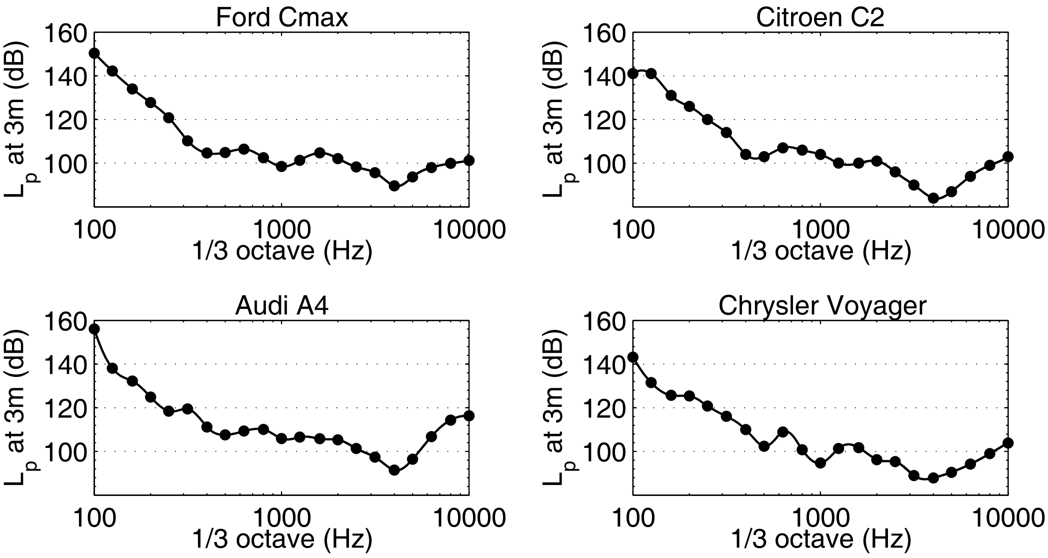

Figure 3: SPL at 3 m for a siren detectable at 60 m from the receiver in one-third octave bands.

3.5 Special Cases

The calculations in previous sections do not account for the increase of interior background noise due to the radio or motorway circulation. The effect of the radio has been studied with the Ford Cmax model. Different spectra for different types of music and talk shows at different volumes have been measured with a sound meter situated in the head of the front passenger and in normal circulation regime inside cities.

The circulation in orbital motorways has been studied also for the Ford Cmax model. The interior background noise has been measured with a sound meter situated at the head of the front passenger and driving at about 80 km/h during 10 minutes. The choice of a given hearing threshold also affects the audibility of the siren inside a car. The hearing threshold used in Section 3.4 is the average for a 60 year old man. However, the hearing threshold is higher if one has to include a larger population. In particular, sirens should be heard ideally by everybody. That means that one should take into account a hearing threshold that includes the 95% of the population with normal hearing.

Figure 4 shows the SPL at 3 m that should have a siren at a given one-third octave band to be clearly detectable inside the Ford Cmax at 60 m from the emergency vehicle, for the special cases of: music at a volume subjectively high, L_p=83 dB, and for a hearing threshold below of which is the 95% of people under 60 years.

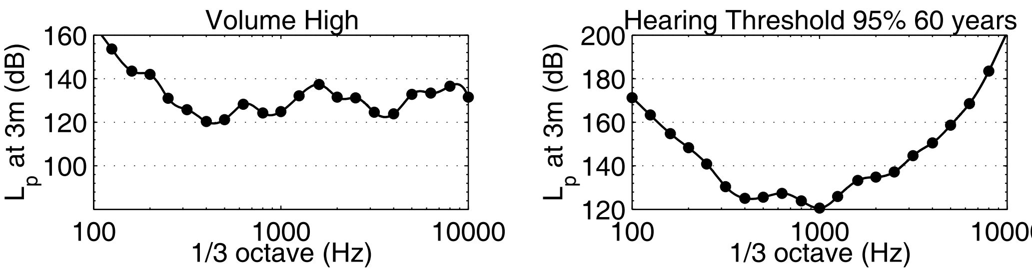

Figure 4: SPL at 3 m for a siren detectable inside a Ford Cmax at 60 m from the receiver in one-third octave bands for special cases of inside background noise and hearing threshold.

These special cases show that for a siren to be detected under any circumstances and by any driver it requires an unreasonably high power output (SPL at 3 m higher than 120 dB). Moreover, they also show that lowering the power output of a siren means that it will be detected by less drivers. As a conclusion a reduction of annoyance by a reduction of the power output means also a higher risk of undetection.

4. NEW TONES

Typical tones for sirens include the Wail, a long period scanning (e.g. from 600 Hz to 1200 Hz at 12 cycles/minute), the Yelp, a short period scanning (e.g. from 600 Hz to 1200 Hz at 180 cycles/minute), the Two-Tones (e.g. 550 Hz and 750 Hz at 68 cycles/minute of the Barcelona Police) and the Three-Tones (e.g. 420 Hz, 516 Hz and 420 Hz followed by a pause at 60 cycles/minute for the Barcelona Ambulances). These tones have the advantage of recognition, they have been around for long time and people recognise them and this favours detectability.

In order to take advantage of the frequency windows observed in Figure 3, new tones have been proposed by extending the scans Wail and Yelp down to 315 Hz and with a Two-Tones and a Three-Tones with frequencies of 400 Hz and 1000 Hz. The annoyance and urgency degree of these new tones have been evaluated by means of a jury test. The list of tones evaluated can be seen in Table 1.

Table 1 – Siren tones evaluated via jury test

#	Tone	Description
1	Standard Wail	600 Hz to 1200 Hz @ 12 cycles/minute
2	New Wail	315 Hz to 1200 Hz @ 18 cycles/minute
3	Standard Yelp	600 Hz to 1200 Hz @ 180 cycles/minute
4	New Yelp	315 Hz to 1200 Hz @ 180 cycles/minute
5	Two-tones	550 Hz and 750 Hz @ 68 cycles/minute
6	New Two-tones	400 Hz and 1000 Hz @ 68 cycles/minute
7	Three-tones	420 Hz, 516 Hz, and 420 Hz @ 79 cycles/minute
8	New Three-tones	400 Hz, 1000 Hz, and 400 Hz @ 79 cycles/minute

The jury was composed by 30 people (20 male and 10 female) between 19 and 60 years old. 16 were under 30 years old and 14 over 30 years old (of whom 8 were between 30 and 40 years old). In the semantic differential test, each member of the jury had to mark three questions against two opposite options after hearing a tone. The three questions were:

1) Do you consider the sound to be: Not annoying at all / Very annoying
2) Do you consider the sound level as: Low / High
3) Does the tone conveys: Low urgency / High urgency

The power output of the siren's amplifier was cut down to a level that can be tolerated during the approximate ten minute test. The listener had to put a tick on a line scale from −3 to 3 for each question. The test began with a training comprised of the standard tones that were played again during the test. The training marks were rejected. For each jury member their scores were normalised as to have zero mean and unit standard deviation. The mean and standard deviation for each question and tone are plotted in Figure 5.

The wail tones are perceived as less annoying but also convey less urgency. All wail tones were considered equally annoying and urgent. So the use of the New Wail tone would improve the detectability of the siren without provoking more annoyance or reducing the urgency sensation.

The New Yelp tone offer the same conclusions, the new tone is not more annoying than the standard tone and conveys the same level of urgency. However, the Yelp is more annoying and urgent tone than the Wail.

On the contrary, the new Two-tone and Three-Tone are more annoying than their standard counterparts. So their use, although improving their detectability, would introduce more annoyance to the citizens.

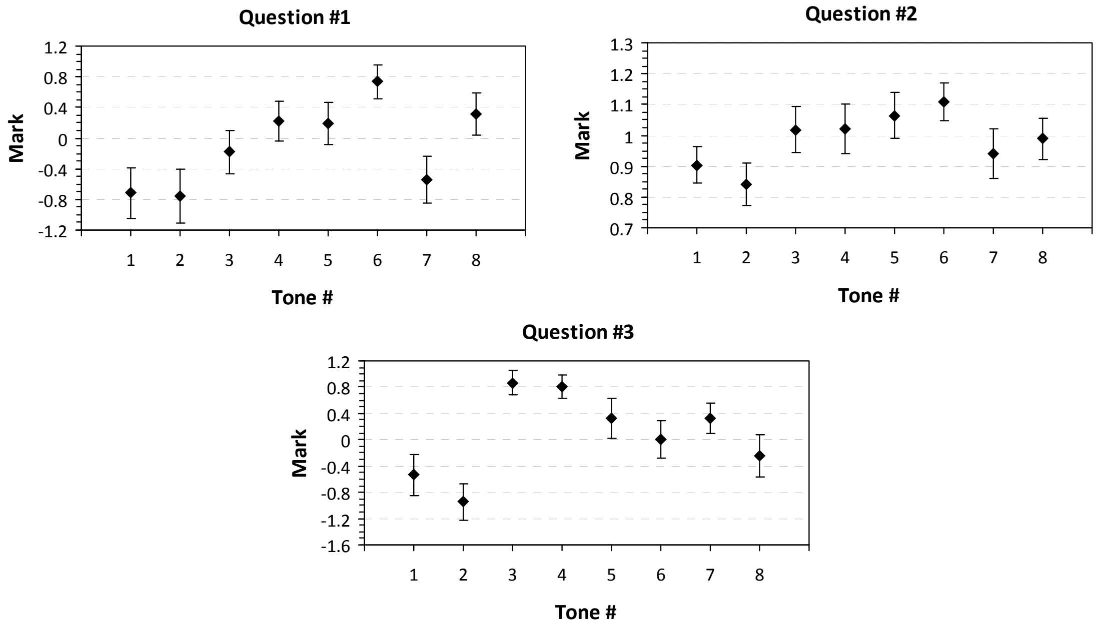

Figure 5: Jury test results.

5. CONCLUSIONS

The present study aims at reducing the annoyance to citizens produced by the sirens in emergency vehicles by refining their power and frequency.

The power requirements indicate that the SPL inside the receiving car must be equal to the masked hearing threshold plus 15 dB in order to ensure detection. To this level one has to sum the car insulation and propagate it to the required security distance.

In order to carry out these computations it has been measured the insulation and interior background noise in normal urban driving for ten different cars.

The main conclusion is that acting over the siren's power might create a safety problem. However, there exists the possibility of increasing the detectability of a siren without increasing either its power or his annoyance by changing the frequencies at which the sirens emit.

It has been shown that there exist two frequency windows with optimum combination of high auditory efficiency, low car insulation and low background noise. As a consequence, sirens emitting in the 400 Hz and 1000 Hz one-third octave bands are detected from longer distances.

A jury test shows that new tones of Wail and Yelp from 315 Hz to 1200 Hz do not increase the annoyance created by the siren. On the other hand, the inclusion of a 1000 Hz tone in a Two-Tones or Three-Tones siren increases the annoyance, albeit they also increase the detectability.

ACKNOWLEDGEMENTS

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