DESIGNING AND DELIVERING THE RIGHT SOUND FOR QUIET VEHICLES

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ABSTRACT

Creating the right sound for quiet vehicles is extremely important. External warning sounds must reflect the vehicle brand image and be accepted by owners, whilst having good warning characteristics and harmonising with the environment. Internal sounds can be used to convey vehicle status, whilst enhancing the brand and driving pleasure. Since these vehicles are quiet, there is much broader scope for styling the sound that they should make. However, evaluating and selecting alternative sounds is extremely time and labour intensive if done in the real world because of the large number of vehicle and environmental factors which can influence the perception of the sound, especially outside the vehicle.

This paper outlines a process where the exterior and interior sounds of vehicles are evaluated efficiently in the virtual world. The consensus derived from subjective jury can be gathered quickly and cheaply, leading to a shortlist of sounds to be tried on a real vehicle. It introduces a toolset which uses the same data and algorithms for designing sounds in the virtual world and validating them in the real world. The same data can also be used directly in a production series by embedding the software algorithms into the production vehicle hardware.

Keywords: Sound Quality, AVAS, hybrid, EV, HEV

I-INCE Classification of Subjects Number(s): 76.9, 73.6, 63.7, 13.2

1. INTRODUCTION

Quiet Vehicles (by which term we mean any vehicle moving without a running internal combustion engine) can move extremely quietly at significant speed, especially on smooth or low noise road surfaces. This can create dangerous situations where pedestrians or other users of the road (or car park) are unaware of the vehicle and so do not react to its presence in the usual manner (1). Concern has been raised to a level where there is proposed legislation on the minimum level of sound (Quiet) Vehicles must emit to warn other road users of the approaching vehicle(2). The audible warning system delivering these warning sounds has become known as "AVAS" or "Approaching Vehicle Audible System". Since there is no mechanical system in these vehicles which naturally emits sufficient noise at low speeds, AVAS systems are usually electronically synthesised, and there is therefore almost no limit to the characteristics of the sound which can be created by AVAS.

Inside the Quiet Vehicle, whilst many have looked forward to the removal of the "noisy engine", the resulting sound whilst driving through the speed range is often an unbalanced mix of road, wind, and sometimes other "feature" sounds which are not desirable. To add to this issue, there is very little positive intrinsic sound quality in road or wind noise, so the opportunities for OEMs to use sound as a way of expressing their brand identity is greatly reduced. Many vehicle manufacturers are therefore considering adding sound internally to provide the driver feedback on the vehicle condition, battery condition, and / or driving style, and at the same time to mask some of these unwanted sounds or to balance the soundscape. As with external sounds, these will be added by some synthesised means, and again there is almost no limit to the characteristics of the sound which can be created.

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This paper outlines a process for developing these sounds for Quiet Vehicles and AVAS systems which is significantly more efficient than the conventional process.

2. THE REQUIREMENTS OF SOUNDS FOR QUIET VEHICLES

The list of requirements for successful implementation of both exterior and interior sounds of Quiet Vehicles is demanding.

In the case of exterior sounds, the sounds have to:

- Be good warning sounds to other road users, so in addition to being detectable or noticeable above the background environment, they should attract attention without being annoying or overly alarming.
- Inform the listener about the car (localisation, speed, acceleration).
- Provide a positive, and if possible uniquely identifiable, image of the brand values of the vehicle and manufacturer.
- Be sympathetic to the urban environment.

Often, all these requirements are in conflict.

In the case of interior sounds within the Quiet Vehicle cabin, the sound should

- Provide aural feedback to convey a better sense of the status of the car, or possibly even the efficiency of driving style. This means it has to adapt to vehicle parameters such as pedal position, torque request, speed, rpm, or battery condition for example.
- Be designed to mask unwanted sounds which cannot be viably reduced or removed, and to help balance the road and wind contributions.

In some cases, manufacturers are also allowing customers to express their individuality by selecting sounds from a library of options.

Whilst it may seem that freedom from the usual constraints of tuning the sounds of mechanical systems is a benefit, designing a sound to satisfy all the requirements for these sounds is challenging. To convey the most appropriate information, the sounds usually vary proportional to one or more vehicle parameters, so it is necessary to design a sound and evaluate how that sound would or should change with those parameters. In addition to that complication, the vehicle from which exterior sounds are emitted is moving relative to the observer, which adds further changes to the sound not only through Doppler shift but also localisation effects. It follows that what sounds good as a “static” file played at a desk on headphones may not sound good when dynamically pitched, Doppler shifted and moving about. It is therefore likely that there will be many candidate sounds which need to be tried out.

3. A PROCEDURE FOR DEVELOPING SOUNDS FOR QUIET VEHICLES

As well as having to design a sound or signal to play, we also need an efficient way to develop and test those signals, and an optimised system to deliver them on production quiet vehicles. These three requirements are inter-dependent: the type and complexity of the sounds which are designed affect and are affected by the type and complexity of the sound system required to generate them, both in production and during development.

3.1 A Conventional approach

A conventional approach is to create, or record, a set of sounds using any suitable system, fit a synthesis system to the Quiet Vehicle (often pitched wave synthesis and speaker delivery for initial trials), download the sounds onto it, and test them one after another by driving it. In the case of exterior sounds, the test vehicle is driven past a group of observers in series of set manoeuvres (scenarios), for example vehicle approaching from behind, passing and turning into a junction in front of the observers.

Figure 1: Testing sounds using the Conventional Approach

There are significant difficulties to get a consensus of opinion when using this approach because of poor repeatability of each test condition. The sounds vary according to vehicle parameters requiring precise driving, the traffic and other ambient sounds are continually varying, and even the weather affects the results. In addition to these issues, a large number of assessors need to be moved between many different scenarios, usually requiring repeated tests, which in itself can be a logistical challenge. This process takes significant time, especially where the number of candidate sounds is large.

3.2 Design in the virtual world, deliver in the real world.

A robust, efficient alternative process for evaluating these sounds, together with suite of enabling tools, has been developed. It is split into 3 phases.

1. Sounds are evaluated in the virtual world using an NVH Simulator with interior and exterior evaluation modes. This allows efficient development and evaluation of the sounds in a consistent and repeatable environment to establish a short list of options or maybe even the one selected sound.
2. An optional final, real world validation of the resulting short list of candidate sounds, which can be downloaded directly from the NVH Simulator onto a synthesiser designed for on-vehicle use.
3. Optimise the synthesis system for production use to suit the selected sounds.

3.3 Phase 1: Developing and assessing sounds in a virtual environment

The NVH Simulator enables a controlled evaluation of many potential sounds in a wide variety of realistic scenarios, by a large number of people from a broad range of demographics, safely and in a short time. It has a fully featured interactive sound synthesis capability which can generate a wide range of characteristics, from the precise sound of a specific vehicle, through sounds which are car-like or music based, to sci-fi or “future” based sounds (2,3).

In interior evaluations, the simulator generates the sound heard at each of the listener’s ears. This sound can be synthesis of recorded sound at that location, or be the sum of a set of contributions from different noise sources on the vehicle. Each sound can be modified in real time to allow the user to tune the overall impression towards the desired outcome (Figure 2a). It is also possible to use the system, in combination with a suitable vibration generation rig, to develop vehicles for vibration as well as sound (1).

Similarly, in Exterior mode, each sound source on the moving vehicle can be represented in the simulation, such that for example each tyre has its own individual noise source at the correct location, as does the AVAS system source and any other significant source on the vehicle (Figure 2b). The NVH Simulator synthesises the exterior sounds of the vehicle moving through a scenario as heard by an external observer, who can also move. The sound from each defined source is calculated at the ears of the observer, taking into account ground plane reflections, absorptions, localisation of the source, and source directivity. By adjusting data and synthesis parameters, the NVH Simulator can easily be used to evaluate and tune the characteristics of the AVAS sound, and the parameters used to control it, to develop the right settings to give maximum information to the listener e.g. localisation of the car, its speed and acceleration. (2, 11).

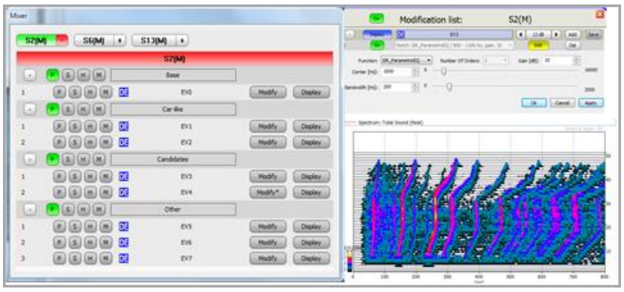

Figure 2a: Multiple source contributions are tuned to deliver the optimum sound experience whilst driving

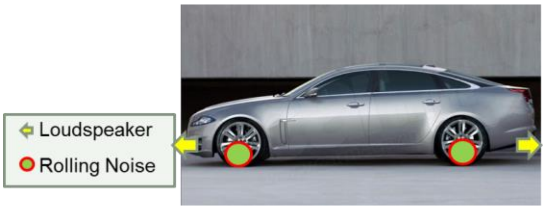

Figure 2b: Multiple Sound sources are represented for exterior modelling

In the simulation, the vehicle can carry out any manoeuvre and the observer / listener can be stationary or moving through the scene. For exterior sound evaluations, the general scene selected usually consists of a typical urban townscape, providing most opportunities to evaluate low speed, high proximity scenarios which are important for AVAS system design.

No matter how efficient the virtual evaluation system is, it is still not possible to test every sound in every possible scenario and background environment. It follows that, just as in the real world, a set of scenarios must be chosen in which to test the sounds being developed. Figure 3a shows a route through the town highlighting four typical detail scenarios: a pedestrian crossing, vehicles turning left (or right) around a corner, a straight road with a bus stop, and a car park. Figure 3b shows some scenarios from observer viewpoint. In addition to having complete control over the traffic (also with representative sounds), background sounds can be selected (or user recorded sounds can also be used) to represent different levels of town activity, or other potentially audible features such as waterfalls or fountains. This combination of controlled visual and auditory background stimuli allows the system to be used to evaluate detectability, sound appeal and environmental annoyance in a repeatable, controlled process. (11, 12, 13, 14).

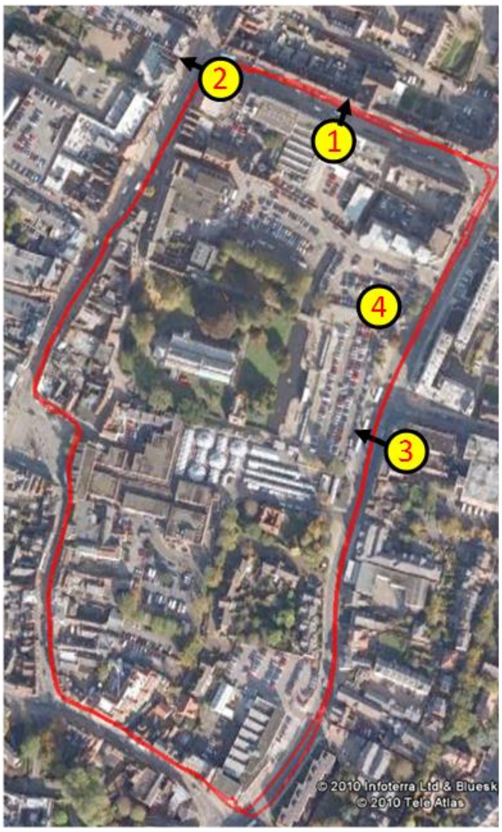

Figure 3a: Typical town scene.

Figure 3b: Scenarios: In town and open road

The usual procedure for developing sounds in the NVH Simulator is therefore to:

- Define a set of scenarios for which to design your sounds, and therefore in which to evaluate them.
    - In the case of interior sounds, these are likely to be a mix of dynamic smaller roads on which to test driver engagement, and motorway to evaluate prolonged cruising comfort. Town scenarios can also be used especially if the vehicle is designed for urban use.
    - For exterior sounds, these scenarios are usually a set of low speed, high proximity scenarios, for example quiet vehicles pulling out of obscured parking spaces in the car park, cars turning across the path of a pedestrian at a road junction, etc. [3] These scenarios can be recorded by driving the Quiet Vehicle through the scenario, and then by recording the path of the observer (or listener). These two trajectories are combined in a simple editing tool so that the combined scenario is as desired in a timebased "performance" file. Using this file to control the simulation enables the system to provide total repeatability, although the system can also be used in a free-driving or "free-walking" mode.

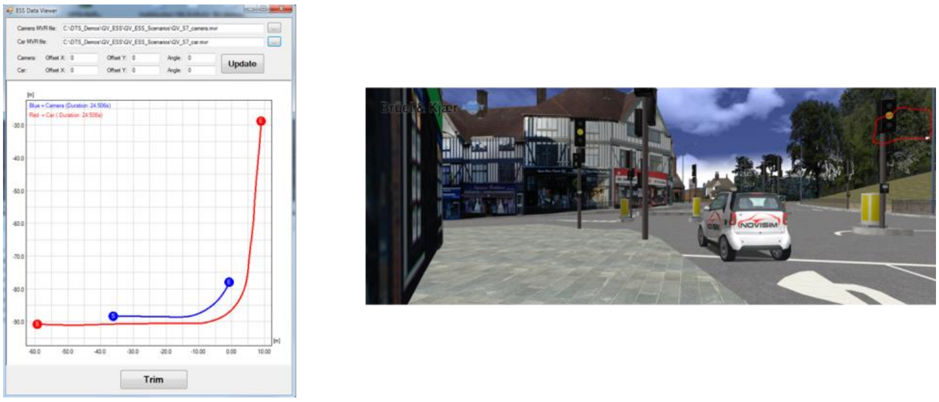

Figure 4: Combining trajectories for a Left Turn at Traffic Lights Scenario

- Define an initial set of sounds to evaluate (set targets). Initially this requires involvement from the brand guardians to aid decisions as to whether the sounds will be in the style of existing powertrain (engine sounds) or not. Sounds can be based on recorded or sampled sounds, decomposed into engine harmonics or not as appropriate, or totally synthesised using the order designing functionality which allows users to create an engine type sound from scratch. Sounds of varying richness or complexity are often used to identify the sound quality requirements for the brand. For vehicles which are going to use a synthesis system, and especially if recognisable sounds are chosen, for example the sound of an engine, the quality of the sound synthesis is extremely important if the resulting experience for the listener is not to sound synthetic. The louder the added sound is over the background sound, the more this applies. Often the initial selection of sounds include fully complex sounds, either recordings or synthesised, but as the work progresses it is usual to attempt to reduce the complexity of sounds to reduce the complexity and cost of the synthesis system required to deliver them in production. A compromise between cost and a fully featured sound can be reached in this way.
- Assign the sounds to the simulated Quiet Vehicle and let it drive through the scenarios, adjusting the parameters controlling the sounds until the result is ready for formal evaluation.

- Run evaluations. There are many different types of evaluation available to suit the user and the assessors.
  - For interior evaluation, the assessor drives the vehicle through various scenarios selecting and assessing various sounds usually whilst "free-driving", or driving interactively. A rating, paired comparison, or semantic evaluation test type is often used, with semantic descriptors in the test which are deemed relevant to the brand image or impression that is desired (4, 5, 8, 10). Figure 5a shows a typical rating style interface for free driving.
  - For exterior AVAS evaluations, usually a "detect rating" type interface is used, where assessors are asked to press a button as soon as they are aware of the presence of the vehicle. In addition, they rate the sound for some sound quality descriptors which are relevant to the brand and also diametrically opposite such as how "powerful" and "refined" was the impression of the sound (11, 12). Figure 5b shows a "rating detect" interface, where there is a button to press as soon as the approaching vehicle is detected, after which ratings are made on the quality and impression of the vehicle.

Figure 5a: Rating interface

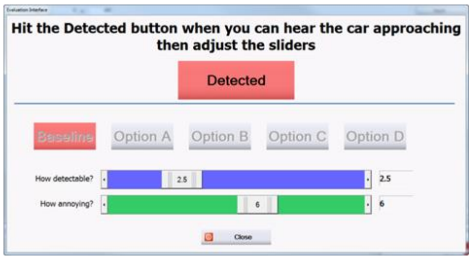

Figure 5b. "Rating Detect" Interface

In the case of exterior evaluations, by using headphones for sound replay and a large projection screen, it is possible to run such evaluations with multiple jurors all voting on tablet devices. This further reduces the time for assessments by a factor of the number of concurrent assessors.

One significant benefit of the virtual system is that it can be used, quickly and easily, to create a scenario where there is not just one Quiet Vehicle in the scenario, but a lot of them. This allows the designer to check that a sound which may be wonderful in isolation doesn't become terrible when multiple vehicles using it are in the same vicinity. It also quickly demonstrates that AVAS sounds need to be designed or even legislated with particular care, since a scenario with many different AVAS sounds, especially those with high modulation, can create a truly terrible environment.

This process of design, development and assessment in a virtual environment provides a rapid route to consensus on the sounds to be deployed. It is quite usual to find that a small number of sounds, usually from the many that were initially trialed, score reasonably well and need a real world trial for final selection and validation.

3.4 Phase 2: Evaluating sounds in the real world

The next step of moving to the real world has multiple purposes. As most of the sound selection has been done in the simulator, this phase of the work provides a post validation that scores obtained in the simulator were reasonable when compared to the real world results, and that the scenarios used in the simulator were adequately prepared to ensure the sound is heard as expected. It also starts the process of selecting and validating the sound delivery system on the vehicle. This is usually split into two parts – the synthesis system, which generates the signal, and the sound generation system which turns that signal into sound.

The synthesis system is fundamental. It needs to be able to deliver the desired level of sound complexity or richness. Often for validation purposes some of these sounds are more complex than the ideal production intent. It is simplest to use a synthesis system that uses the same data structure and algorithms as the simulator, since the data can be simply copied onto the system as opposed to reformatted. The VSound system that partners the NVH Simulator, like its stablemate, is capable of delivering totally natural and realistic powertrain sounds synthesized from sets of order amplitudes and phases dependent on rpm and 'gas pedal' position. In addition to this it can deliver random based sounds (such as road or wind masking) proportional to one or two parameters, combustion noise, and also pitchable loop and simple wave file replay. The pitchable loop algorithm is widely used for production AVAS sounds since it is very cheap computationally. The system can replay many of these different sounds at the same time, allowing richness and complexity of sound to be built up. The system is controlled by CANbus or FlexRay, and is totally configurable – each sound in the system can be independently controlled reacting in user specified ways to user selected parameters from the vehicle.

The VSound system has been implemented in a PC / tablet based format for quick development using other tools to modify data even during a development evaluation, and a DSP based system suitable for long term, unmanned trials on the engineering fleet (Figure 6).

Figure 6a: VSound on Tablet

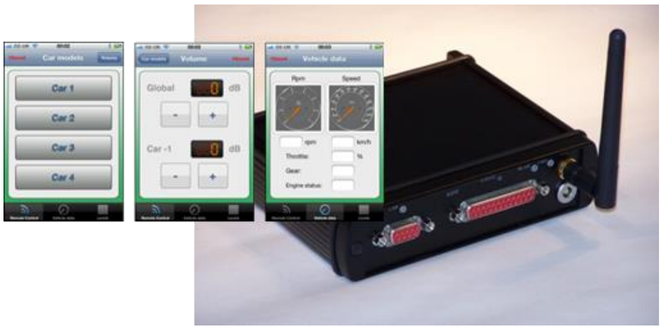

Figure 6b: VSound on DSP with remote control app

Often the sound generation system coupled to the synthesis engine is an amplifier and loudspeaker, but it can also be more radical such as panels of the vehicle driven by exciters. This potentially brings reduction in mass and complexity. In the case of interior sound enhancement, it can be as simple as plugging into the auxiliary input on the in-car entertainment system.

It is true that all the issues with the conventional approach apply at this phase. The benefit of having used the simulator first is that the number of candidate sounds is now low, the statistical significance of results should already be satisfactory, and therefore it is possible to run a much smaller evaluation in terms of number of candidate sounds and number of evaluators.

The process in this phase, following from the virtual phase, is to download a subset of candidate sounds from the NVH Simulator onto the VSound system and install it into the vehicle. Identify a set of scenarios and / or locations in which to evaluate the sounds, and select a small cross-sample of jurors to evaluate the sounds and validate or make any final decision.

3.5 Phase 3: Optimising the sound delivery system

There are manufacturers and applications where the result of this process to this point is used as the target definition for a sound which will be delivered by modifications to the structure and components of the vehicle (i.e. not using an electronic synthesis engine and sound generation system). In this case, identification in the NVH simulator of suitable vehicle component contributions which can be modified to generate the desired sound now lead to measurements or calculations of the required transfer functions and source strengths required, and detailed design work on these components can start.

For vehicles which are going to use a synthesis system, the task is now to select and optimise a system for production. Depending on the required complexity of sounds, which should have been determined in the simulator evaluations, a “bolt on” synthesis system can be selected which has the necessary performance at the right price, or if that cannot be found, a custom solution must be developed. Since the requirements of manufacturers is to reduce weight and complexity of vehicle systems, it makes sense to integrate similar systems together if possible, and the natural place for a sound synthesis algorithm to be is in the amplifier of the in-car entertainment system. Economically it makes sense for vehicle manufacturers and audio suppliers to embed this system generically when new audio systems are developed, so that integrated AVAS and sound enhancement solutions are available as required throughout the life of the audio component.

The VSound algorithms, including the capability to generate totally natural engine sounds based on harmonic synthesis, are now able to be embedded into audio amplifiers. This is a totally custom solution, where only the necessary algorithms of VSound required to develop the required, and predicted, complexity of sounds are embedded onto a DSP running inside the amplifier. The sound generation system can be the existing speaker system inside the vehicle, where the ever increasing number of loudspeakers provides for a more natural reproduction, or additional speakers or panel exciters fitted inside or outside the cabin.

4. CONCLUSION.

A process has been summarised which optimizes the work to develop and deliver the right sounds for Quiet Vehicles. This process is also applicable for designing and delivering sound enhancement in more conventional vehicles, and can be illustrated as in Figure 7.

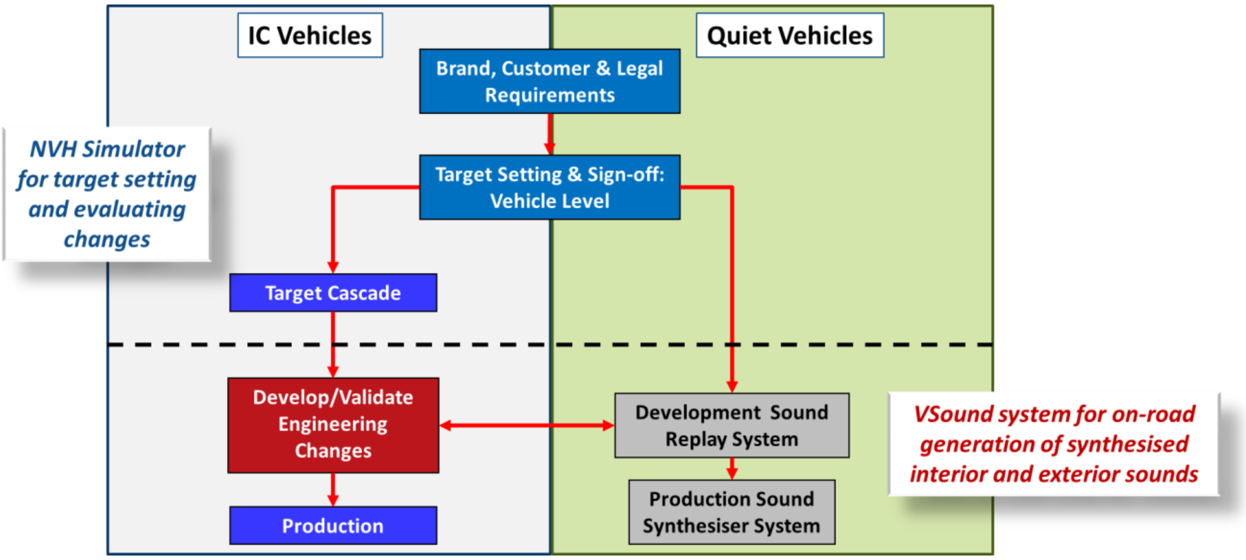

Figure 7: A process to design and deliver the right sounds

The provision of VSound algorithms embedded into production amplifier systems is the final tool to complete the chain, providing the possibility to develop sounds in the NVH Simulator, evaluate them in an optimised virtual environment, download the sounds onto a test system for final validation in a real environment, and copy the data directly onto a production vehicle using an optimised production solution. The benefit of such a process and capability is that sound style can be developed quickly, and that it can be signed off very late in the vehicle development process, since it only has to be downloaded onto the amplifier during or just before production.

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