A Consideration of Methods for Controlling Reproduced Audio Dynamic Range in the Noisy Environment Created in Vehicles

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Abstract

Audio reproduction in vehicles usually comes with the phenomenon (called masking) in which some reproduced sound is always drowned out and made inaudible due to noise in the moving vehicle. Fujitsu Ten is now commercially producing the Automatic Sound Levelizer (ASL) as a function for making it easier to listen to reproduced sound in a noisy vehicle. However, the current ASL still has problems, such as noticeable changes in sound level. To solve these problems, we are now considering applying a dynamic range compressor to ASL as a new means for correcting reproduced sound level. This document introduces our established methods of deriving optimum dynamic rage compression characteristics according to noise, which are necessary to apply a dynamic range compressor.

1. Introduction

When sound is played back inside a vehicle, it is always accompanied by road noise masking. Masking is a phenomenon that is characterized by the fact that when two different acoustic signals exist simultaneously, the signal with the greater volume conceals the other signal so that the latter signal cannot be heard. Although various approaches are available to avoid the effects of such noise masking, they can be broadly divided into two methods. The first is a method that reduces the noise itself, and the second is a method that compensate the reproduced sound. Our company has selected the latter method of correcting the reproduced sound, and is considering the application of a dynamic range compressor as a means to achieve this. In connection with the introduction of this dynamic range compressor, we have been able to establish an indispensable method of deriving optimal dynamic range compression characteristics for noise. That method will be reported here.

2. Audio reproduction problems related to road noise

When sound is played back inside a vehicle, it is affected by road noise masking. Because of such masking, the low-volume portion of the reproduced sound is covered by the road noise, making the sound difficult to hear.

Figs. 1 and 2 diagrammatically show the effects of masking due to noise. For the dynamic range that naturally exists in reproduced sound (range of volume change), when there is no noise as shown in Fig. 1, all of the sound volume change shown in (a) can be heard as is. When there is noise as shown in Fig. 2, the volume range that can actually be heard diminishes as shown in (b); while the sound in portion (c), which is covered by noise, can no longer be heard. For this reason, the listener must often adjust the volume controls according to the travel conditions. This is not only irritating but can diminish safety.

3. Conventional corrective measures

To solve such problems caused by masking, our company has developed a noise-sensor-equipped control (automatic sound levelizer, or ASL), which is currently being commercialized. Its operating principles and weaknesses will be described hereinafter.

3.1 ASL operating principles

A simple explanation of the ASL's operating principles will be given here. Fig. 3 shows its configuration. First, noise is detected by a microphone that has been installed inside the vehicle, and the volume of the noise is calculated. An appropriate volume correction that corresponds to the noise volume is then added to the normal volume. In this way, the overall sound volume is increased, making it possible to hear the low-volume portions of sound that were covered by noise and could not be heard. This has the effect of eliminating noise masking.

3.2 ASL weaknesses

The automatic sound levelizer (ASL) makes it possible to automatically adjust the volume according to changes in road noise, eliminates noise masking, and eliminates the need for listeners to constantly adjust the volume. However, since this system employs a method that controls the volume itself, listeners may at times feel fluctuation due to the change in overall sound volume that accompanies the change in noise. For this reason,

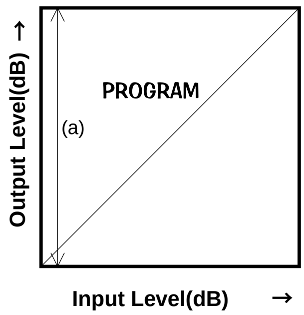

Fig.1 Explanation of Masking (when there is no noise)

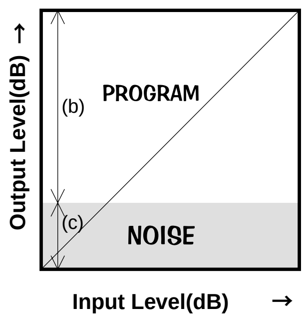

Fig.2 Explanation of Masking (when there is noise)

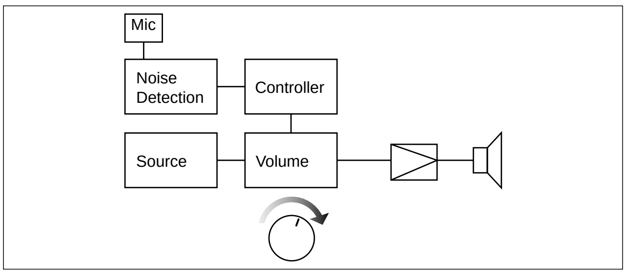

Fig.3 ASL Block Diagram

improvements were sought for the purpose of producing natural corrections that left listeners free of any sense of volume change.

4. Noise-sensor-equipped dynamic range compressor

In order to develop a new ASL to solve problems associated with conventional ASLs and to "ease listening and produce a sense of sound volume levelness," it is necessary to correct the volume range of the reproduced sound (= dynamic range) rather than simply correct the sound volume. One possible solution being considered is the application of a "dynamic range compressor" to compress the dynamic range.

4.1 Operating principles

First, let's examine the operation of the dynamic range compressor.

A dynamic range compressor is a function that compresses the dynamic range of reproduced sound. By reducing large sounds and enlarging small sounds, it works to minimize the overall range of sound volume change. Using this dynamic range compressor helps to produce appropriate compression characteristics, raises the volume of low-volume portions of sound that are masked by noise, and maintains the present volume of high-volume portions of sound that are not masked. As a result, it becomes possible to hear low-volume portions of sound that would normally be covered by noise, without changing the listener's overall sense of the sound volume level (Fig. 4).

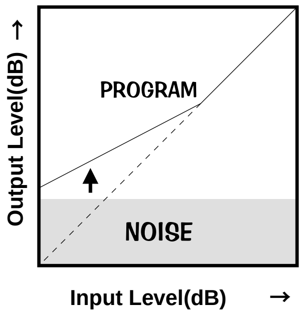

Fig.4 Explanation of Compressor Operation

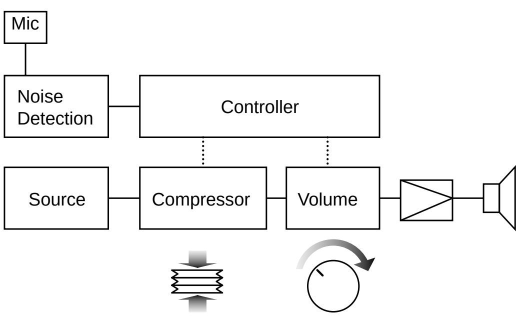

Fig.5 Noise-Sensor-Equipped Compressor Block Diagram

The effects of masking change according to noise conditions, so different compression characteristics are necessary for appropriate correction. By constructing a "noise-sensor-equipped dynamic range compressor" that changes the compression characteristics according to changes in the noise, it becomes possible to produce natural corrections with minimal discernible change in sound volume level. The configuration is shown in Fig. 5.

5. Deriving dynamic range compression characteristics

The compression characteristics of the dynamic range compressor are represented by input-output characteristics such as those shown in Fig. 4. To ready the product for the market, however, it is necessary to find compression characteristics that evade the effects of masking due to noise. This chapter will explain a method of deriving dynamic range compression characteristics using a psychological test.

5.1 Selection of simulated noise

A certain psychological test sought to find a correction for music signals masked by road noise. Actual road

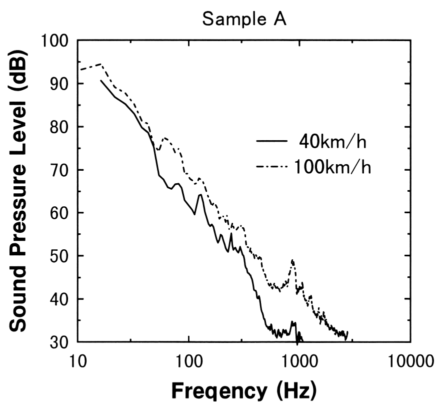

Fig.6 Examples of Noise in a Moving Car (Car Model A)

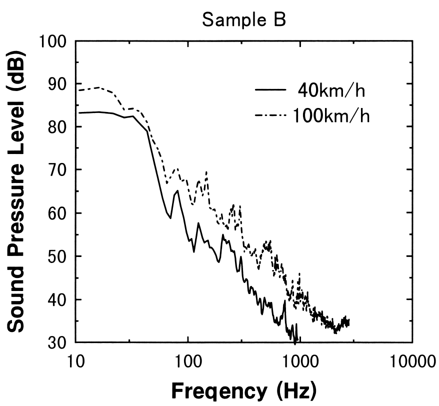

Fig.7 Examples of Noise in a Moving Car (Car Model B)

noise, however, as shown in Figs. 6 and 7, has characteristics that differ according to the type of vehicle, travel speed, and other factors. During product development, it is difficult to adjust the compression characteristics for each vehicle type and for the various parameters that express noise. For this reason, we examined setting up similar noise used for psychological tests to enable control while focusing only on changes in the noise level (units of dB(A)) as the parameter.

To simplify the similar noise as much as possible, the examination consisted of comparing white noise that had passed through a filter a spectrum of real noise (comparison of least square error).

To produce typical similar noise, the following three types of vehicles were selected, since their road noise characteristics were thought to differ. Data taken from four travel speeds (40, 60, 80, and 100 km/h) was utilized.

(Vehicles used during comparative examination)

① Crown Royal Saloon (sedan, 6-cylinder)
② Altezza (sports type, 4-cylinder)
③ Land Cruiser (recreational vehicle, 8-cylinder, V-type)

As a result of examination, it was assumed that sound produced by passing white noise through a -9 dB/oct filter would have the smallest error (calculated using least squares), so this was assumed to be the similar noise. Fig. 8 shows an example of a spectrum comparison of real noise and similar noise.

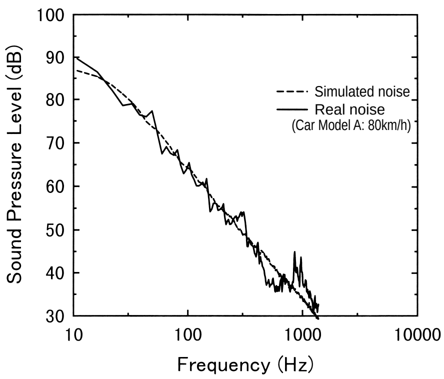

Fig.8 Comparison of Similar and Real Noise Spectrums

5.2 Verification I: effectiveness of similar noise (vehicle type differences)

An examination was conducted as to whether the assumed similar noise could be used in the psychological test for deriving dynamic range compression characteristics. An test for deriving actual dynamic range compression characteristics was conducted as was a similar psychological test using similar noise and actual road noise (produced by three vehicle types); then an examination was conducted to see if there were any significant differences in the results. Fig. 9 shows a block diagram of the psychological test, while the test procedure is shown below.

(Test procedure)

① Listen to a program of reproduced sound under conditions that are free of noise.
② Add noise.
③ Listener adjusts volume of reproduced sound until the programmed sound can be heard just as in the noise-free conditions (listener adjustment).
④ Find the aforementioned adjusted sound volume (amount of volume correction necessary) for each program sound volume and noise level.

The various test conditions are described below.

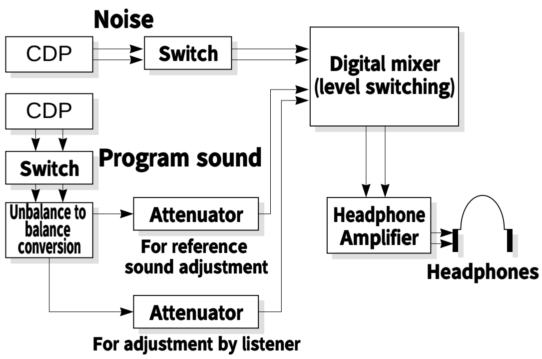

Fig.9 Psychological Test Block

- Listeners: 10 (aged 25-35 with good hearing)
- Program contents: NHK news announcer (male) (program that enabled easy regulation of sound level)
- Program volume: 40, 50, 60, 70, and 80 dB(A) (5 types)
- Noise: Actual road noise of three vehicles (collection of road noise from Crown, Altezza, and Land Cruiser), similar noise (sound produced by passing white noise through a -9 dB/oct filter), aforementioned all monophonic
- Noise level: Actual road noise was noise produced by vehicle traveling at 40, 60, 80, and 100 km/h; while similar noise corresponded to noise level at each travel speed.

5.2.1 Test results

Figs. 10 and 11 show example results (required volume correction). The sought-after correction and population mean were compared and a t examination was conducted. As a result, no significant difference was found based on a significance level (risk) of 5% for the case using actual road noise (three vehicle types) and case using similar noise. From these results, a standard psychological test (deduction of dynamic range compression characteristics), to a certain degree, is thought to be possible using predetermined similar noise.

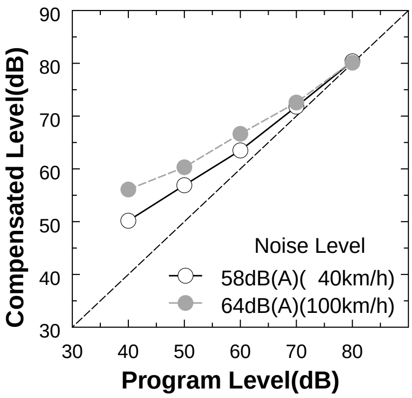

Fig.10 Amount of Required Volume Correction (Crown)

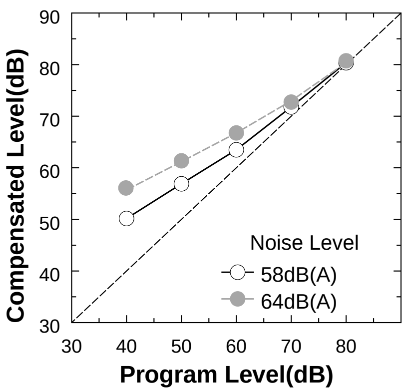

Fig.11 Amount of Required Volume Correction (Similar Noise Equivalent to that of Crown)

5.3 Verification II: effectiveness of similar noise (interaural cross-correlation differences)

Continuing, the effect of interaural cross-correlation (IACC) of road noise will be examined. Interaural cross-correlation refers to the similarity of signals that enter both ears. In the case of monophonic signals, when the signals to the left and right are exactly the same, the interaural cross-correlation is 1. In the case of a completely negative-phase signal, it is -1. In the preceding section, an examination was conducted using monophonic road noise; but with actual road noise, complex interaural cross-correlation values can appear, depending on the frequency. For instance, Fig. 12 shows an example of the interaural cross-correlation of the road noise produced by an Altezza. Since the value changes in a complicated manner depending on the frequency, the interaural cross-correlation is difficult to reproduce with similar noise. For this reason, we will verify whether the similar noise of a simple monophonic signal can be used as a substitute.

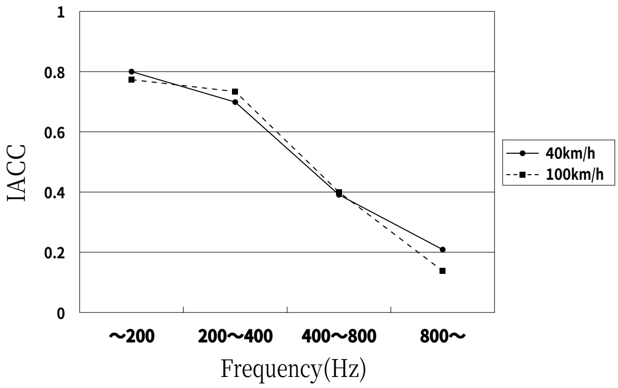

Fig.12 Examples of Interaural Cross-Correlation (Altezza)

The test method is the same as that of the psychological test explained in the preceding section. The noise utilized was actual road noise (three vehicles) that had been collected with a dummy head; then the required sound volume correction was sought. These results together with the required sound volume correction for monophonic noise (from three vehicles) sought in the preceding section were examined for significant differences.

5.3.1 Test results

Fig. 13 shows example results. The sought-after correction and the correction for monophonic sound were compared and a "t Test" was conducted. As a result, no significant difference was found based on a significance level (risk) of 5% for the case using stereo noise (all three vehicles) and case using monophonic noise. From these results, it is thought to be possible to perform an evaluation using monophonic noise without adjusting similar noise to the complex interaural cross-correlation of actual

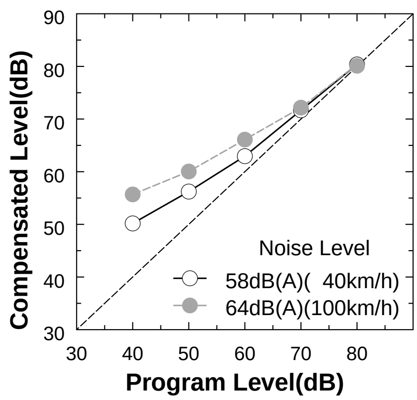

Fig.13 Amount of Required Volume Correction (Stereo of Crown)

road noise.

5.4 Deriving dynamic range compression characteristics

We know that monophonic similar noise can be used in the psychological test in which dynamic range compression characteristics are sought; thus, such similar noise was utilized to find compression characteristics. With the test method being the same as that of the similar noise verification, the sound volume correction required for each noise level and program level was sought.

Fig. 14 shows the results. From the results, it is clear that for the low-volume portions, such as when the noise level is 57 dB(A) (equivalent to Crown at 40 km/h) and the program level is 40 dB(A), compression of approximately 12 dB is sufficient; and for relatively high-volume portions, such as at 80 dB(A), almost no compression is required. When these compression characteristics are applied to each noise level, it becomes possible to implement control by simply using the noise level as a parameter.

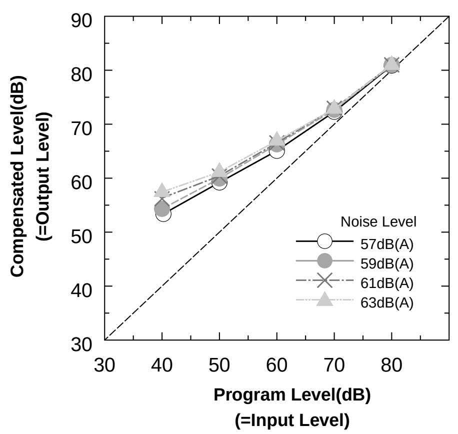

Fig.14 Dynamic Range Compression Characteristics

6. Conclusion

Through this examination, we have been able to establish a method of deriving dynamic range compression characteristics corresponding to noise. In particular, since it has become possible to simplify by using just the volume of noise as the parameter for expressing noise conditions, it has become possible to simplify hardware makeup and processing, which is a great step toward commercializing a product.

In the future, further specific examination of product commercialization is expected as efforts are made to construct hardware that produces dynamic range compression characteristics and the effects due to music signals are confirmed.

Furthermore, for the purpose of "improving the ability to track noise changes," which is another issue and objective of a new ASL, a more advanced noise detection algorithm is also currently being developed. Together with these steps, efforts will be made to complete and commercialize a new ASL that has a natural correction effect and can control discernable changes in sound volume.

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