New AM Noise Canceller

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Abstract

Recently, electrification of vehicle such as the consistent popularization of electric vehicle and hybrid vehicle is accelerating because of responding to environmental problems. Accordingly, the effects on other in-vehicle equipment by electromagnetic wave noise generated by drive-system electronic parts increase. Especially, an in-vehicle AM radio receiver is electric equipment which is easily affected by noise, and development of countermeasure technology for that is expected. DENSO TEN who develops an in-vehicle radio receiver works on maintenance and improvement of the radio receiving quality by the countermeasure on the side of receiving noise.

In accordance with the electrification of vehicle, beat noise and random noise become a remarkable problem. In this paper, we explain outline of the method and the effect of the reduction of noises above as examples, and we introduce our efforts toward noise reduction technology for DENSO TEN AM radio receiver.

1. Introduction

Recently, electrification of vehicle such as the consistent popularization of electric vehicle (hereinafter "EV") and hybrid vehicle (hereinafter "HV") is accelerating because of responding to environmental problems. Accordingly, the effects on other in-vehicle equipment by electromagnetic wave noise (hereinafter "noise") generated by drive-system electronic parts increase.

Especially, in-vehicle AM radio receiver is easily affected by noise because it uses relatively low-frequency broadcast bandwidth. The technology of AM radio receiver was born about 100 years ago, but still it is installed in many vehicles as a standard function. Under today's vehicle environment where the effect of noise increases, the difficulty of the countermeasure on the side of radiating noise has increased. Therefore, we, DENSO TEN who develops an in-vehicle radio receiver works on maintenance and improvement of the radio receiving quality by the countermeasure on the side of receiving noise.

We introduce the several efforts for noise reduction technology for AM radio receiver.

2. Mechanism of noise mix and its effect

There are various mechanisms of noise mix from noise sources which are mounted on vehicle to a radio receiver. We introduce one example.

When driving of EV / HV, the inverter converts DC from the battery for driving into AC, and it drives the motor. At that time, noise is generated because ON-OFF switching of a large current is performed on high speed. This noise conducts not only inverter but also the cable and parts connected to inverter, and the noise radiates from them, too. A part of radiation noise mixes to the radio antenna on the rear glass and the roof of vehicle. **(Fig. 1)** The noise on the radio antenna is converted into audio signal with broadcast wave in a radio receiver. Especially, it easily happens that the noise leads to abnormal sound because broadcast wave of AM radio is modulated with Amplitude Modulation (AM) system.

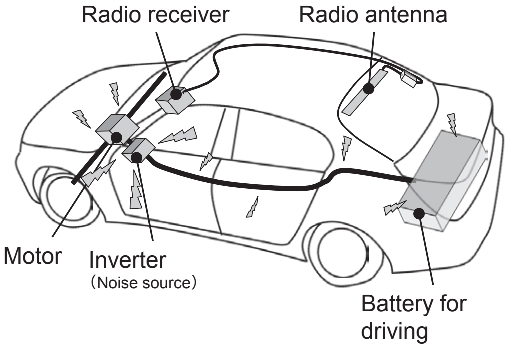

Fig. 1 Noise Mixing Image to Radio Antenna

3. Noise type

Noise on a radio receiver are classified in three groups of pulse noise, random noise and beat noise according to the feature of time domain and frequency domain. These features are shown in **Table 1**.

Table 1 Classification and Feature of Noise (IF signal)[1]

Noise type	Feature of time domain	Feature of frequency domain	Reproduce sound of radio
Pulse	Appear suddenly and for a short time (Time)	Flat distribution (Frequency)	popping
Beat	Sine wave with specified interval (Time)	Peak on specified frequency (Frequency)	peep
Random	Flat distribution (Time)	Flat distribution (Frequency)	skid

* (1) IF: Intermediate Frequency

4. Noise reduction technologies in radio receiver

4.1 Reduction technologies by noise type

DENSO TEN has developed several methods as noise reduction technologies in a radio receiver. **Table 2** shows the list of noise reduction methods which we have already developed until now.

For pulse noise, the method to interpolate a signal by detecting duration using the feature that the peak noise is generated in time domain is effective. The reduction method for pulse noise has been always applied to our products and, we have long experience in the market because pulse noise was generated also as ignition noise of gasoline engine vehicles.

Beat noise shows characteristic waveform in frequency domain, and we studied a noise reduction method using this feature. In accordance with electrification of vehicle, beat noise is becoming serious matter together with random noise, however, a breakthrough noise reduction method has not been materialized yet. Therefore, we have newly developed a method this time. This method is called an adaptive equalization method, and we introduce it in detail in chapter 4.2.

As random noise has no feature in time domain and frequency domain, it is difficult to reduce only the noise. For example, considering the method to suppress the overall signal by detecting noise duration in time domain, we find the effect is limited because the necessary audio is also suppressed when reducing the noise. Therefore, we are newly developing a method which utilizes the noise obtained from the antenna located near the noise radiation source. This method is called a pick-up method, and introduced in detail in chapter 4. 3.

Table 2 List of AM Radio Noise Reduction Method that was developed by DENSO TEN

Noise type	Method	Feature	Issues for commercialization (cost and performance)
Pulse	Time domain interpolation	Interpolate a signal by detecting noise in time domain	–
Beat	Adaptive equalization	Use noise componet appered on Quadrature-Phase after synchronous detection	Change of sound quality when radio wave environment get worse
Random	Noise suppression	Suppress entire signal by detecting noise in time domain	Balance of noise reduction effect and suppression prevention of audio signal
	Pick-up	Synthesize reverse phase with noise signal of pick-up antenna	Need the mounting of additional pick-up antenna

Fig. 2 shows the system block diagram of the AM radio receiver including reduction method of beat noise and random noise in addition to the conventional pulse noise reduction method. The pick-up method works in the Intermediate Frequency (IF) signal, and the adaptive equalization method works in the audio signal after detection.

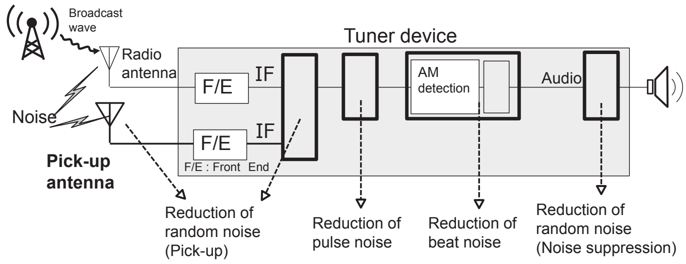

Fig. 2 System Block Diagram of AM Radio Receiver including Noise Reduction Method

4.2 Reduction technology of beat noise

4.2.1 Outline

We elaborate the adaptive equalization method to reduce the beat noise.

There are two methods to demodulate the amplitude-modulated signal. One is the envelope detection, and the other is the synchronous detection.

The envelope detection has been widely used until now because it is relatively simple method. However, mixed noise is directly outputted as the audio sound. On the other hand, the synchronous detection can isolate the noise as described below.

In the synchronous detection, a sine wave that synchronized with the carrier signal (same frequency and phase) is created, and In-Phase, in-phase I component multiplied by the input signal and Quadrature-Phase, orthogonal-phase Q component multiplied by a sine wave of which phase is shifted by 90 degrees from the synchronized signal are created. If a signal with noise is performed the synchronous detection, In-Phase has mixed signal of audio signal and noise, and Quadrature-Phase has noise only. **(Fig. 3)** The reason why noise can be isolated like this is that audio information is included only in amplitude not in phase. It is based on the fact that audio information of amplitude modulation appears in In-Phase only.

We used an adaptive filter to subtract the noise of Quadrature-Phase from In-Phase, which is isolated by the synchronous detection. The adaptive filter is a filter that adaptively changes the characteristic according to the input signal, and it finally becomes to reduce only the noise included in In-Phase.

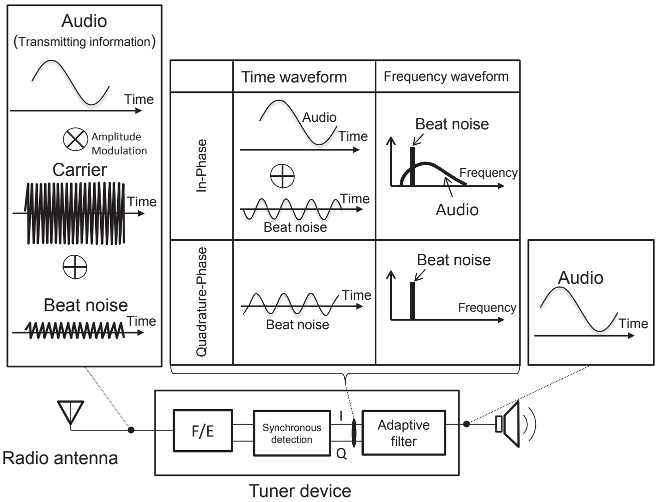

Fig. 3 Conceptual Diagram of Adaptive Equalization Method

Based on this technology, DENSO TEN improved the quality to ensure the performance as the product in cooperation with NXP Semiconductors N.V. (hereinafter “NXP company”) and Catena Holding B.V. (hereinafter “Catena company”) including improvement of noise reduction performance and adaptation for field environment.

4.2.2 Effect of development technology

Fig. 4 shows an example of noise reduction effect in an actual vehicle. It is found that the signal with noise reduction using the adaptive equalization method (red line) can reduce noise with no suppression of audio component, compared to the signal without noise reduction (blue line).

This is one example of noise reduction effect. In order to adapt for various type of the beat noise, we have been verifying the effect by modeling the feature and behavior of noise obtained from the investigation result of vehicle noise and the like. For example, the tracking performance for the noise frequency changing, and ensuring performance for multiple types of noise existing are being pursued. **(Fig. 5)**

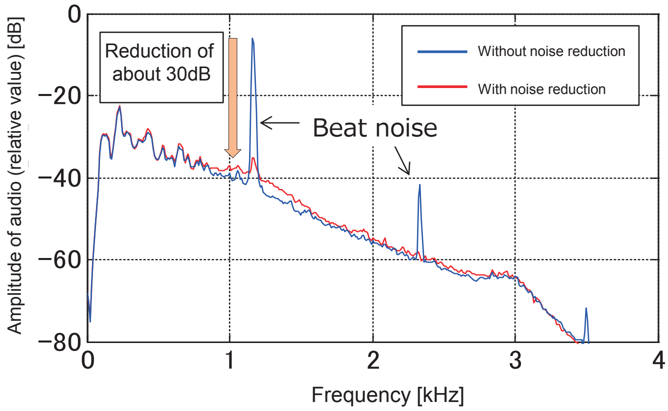

Fig. 4 Audio Output Signal Spectral when Beat Noise mixed

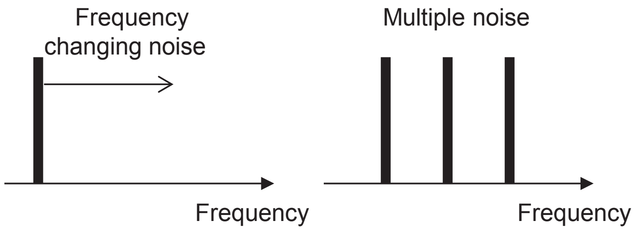

Fig. 5 Example of Beat Noise which confirmed Reduction Effect

4.2.3 Application for field

DENSO TEN took the measures while we identified field environmental condition concerned beforehand. The premise of the adaptive equalization method is correct estimation of the noise by using In-Phase and Quadrature-Phase of synchronous detection. However, under the following three environmental conditions, it is difficult to create the sine wave that synchronizes with the carrier necessary for synchronous detection in the tuner device.

① Weak electrical field strength
② Rapid phase change of carrier signal
③ Same frequency carrier existing

SFN (Single Frequency Network) is an example of environmental condition ③. SFN is an environment that uses the same frequency to transmit the same broadcast wave from the transmitting antennas of several stations. In the area where electrical field strength from multiple transmitting antennas are almost same, multiple carriers with different phases are synthesized. **(Fig. 6)** Therefore, it cannot synchronize with both carriers.

Under these environments, audio component leaks to Quadrature-Phase after synchronous detection. If noise reduction process is performed, attenuation of audio signal level and change of sound quality are concerned.

As for the environment where carrier cannot synchronize, we took a measure of it by adding the block which changes synchronous detection to envelope detection. **(Fig. 7)** Envelope detection is a detection method that doesn't need to synchronize with carriers, and it can prevent change of audio signal. At the timing of switching the methods, uncomfortable feeling was eliminated with blend process, and we adjusted the threshold and the time for switching on bench and in the field environment.

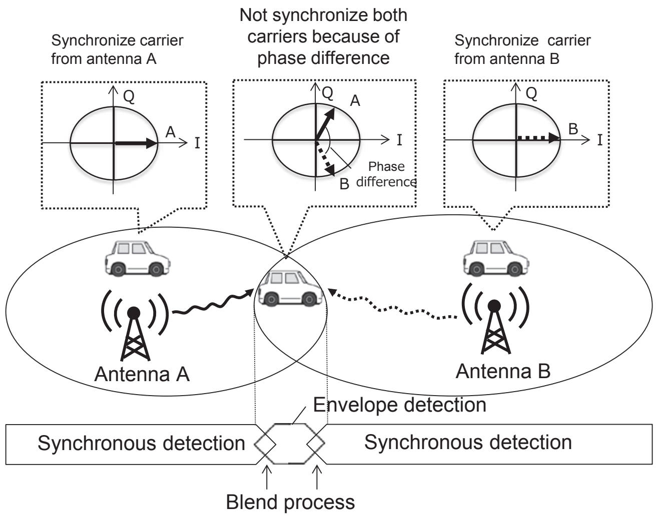

Fig. 6 SFN Environment and Detection Change Process Image

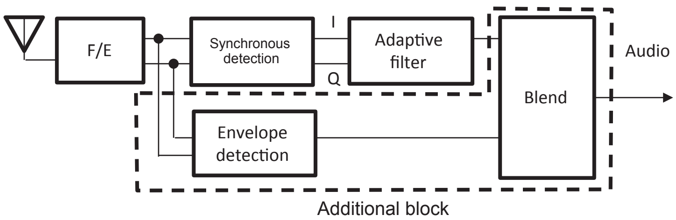

Fig. 7 Block Diagram of Adaptive Equalization Method

4.3 Reduction technology of Random noise

4.3.1 Outline

Next, we elaborate the pick-up method which is developed for reduction of the random noise. **Fig. 8** shows the block diagram of this method. In this method, the synthesized (reversed-phase synthesis) signal adjusting the phase and the amplitude of noise obtained from the pick-up antenna which is located near noise radiation source is outputted so as to cancel the noise that is mixed in broadcast wave. Adjustment of the phase and the amplitude is performed by the control block, which adoptively controls the signal to realize optimum reversed-phase synthesis. As the noise is separately obtained from the signal in this method, we can expect the reduction effect for high level noise into which the carrier signal perfectly sinks down.

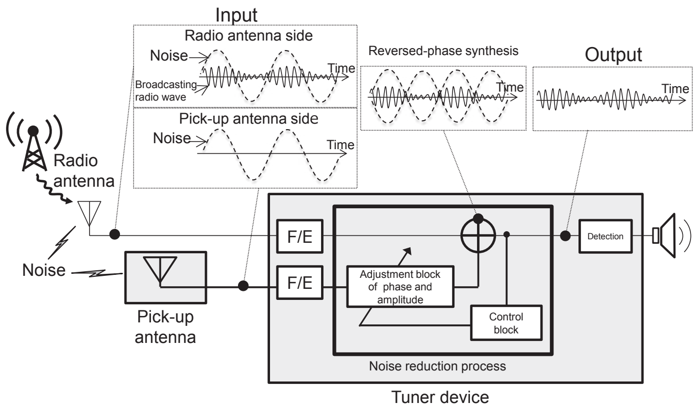

Fig. 8　Block Diagram of Pick-up Method

4.3.2 Effect of developmental technology

The example of noise reduction effect using the pick-up method in an actual vehicle is shown in **Fig. 9**. As for the signal with noise reduction (red line), the noise can be reduced over a wide band compared to the case for the signal without noise reduction. Also it is found that the noise is reduced to the same level of the signal without adding noise (green line), which is obtained in the condition without the operation of noise source of vehicle, in which no noise generates.

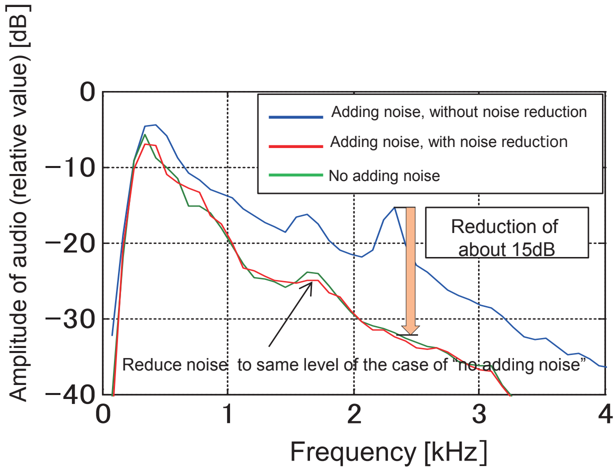

Fig. 9　Audio Output Signal Spectral when Random Noise mixed

4. 4 Future efforts

We have finished field evaluation of the adaptive equalization method for beat noise reduction, and we plan to apply to the next product model. On other hand, as for the pick-up method for random noise reduction, we developed the proto type, and have been investigating the effect for the noise generated from the vehicle. We will perform the field evaluation and others for commercialization.

5. Conclusion

This time, we have newly developed the noise reduction method for beat noise and random noise for AM. As the result, we have been able to develop the reduction technologies for all noise which is classified to three types including already-launched method. As for the reduction method for beat noise, we are approaching the stage of commercialization after development. We will proceed with technical development which can contribute to the improvement of comfort for customers by continuously working on the commercialization of all reduction methods.

Finally, we would like to extend our sincere appreciation to NXP company, Catena company, and all others who cooperate with us.

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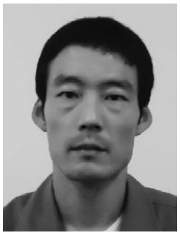

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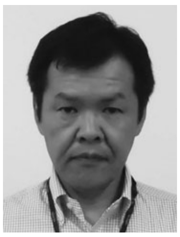

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