

Noise Suppression System for AM Radio Receiver Using Quadrature Component of Receiving Signal

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ABSTRACT

Recently, the electromagnetic interference in an AM radio by the noise generated from a power control unit (DC-DC converters, inverters) in a hybrid vehicle (HV) has become a serious problem. To solve the problem, most noise suppression methods, for example, use noise filters for noise sources and shield wiring and ferrite cores for noise propagation paths. In this paper, we propose a noise suppression method using the digital signal processing in an AM radio receiver. In this method, first the receiving AM radio signal containing HV noise is quadrature demodulated. Next, a replica signal of the noise is generated by using the noise signal in the quadrature component. Then, the replica signal is subtracted from the AM radio signal containing the noise of the in-phase component. We construct a prototype of the radio receiver system based on this method and demonstrate that the system can reduce the HV noise superimposed on the AM radio signal by more than 20 dB. By applying this system to the radio receiver, it is expected that conventional noise suppression methods can be significantly simplified.

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INTRODUCTION

The electromagnetic noise generated from a power control unit (DCDC converters, inverters) in a hybrid vehicle (HV) causes interference in an AM radio, as shown in Fig. 1 [1]. For this problem, noise suppression methods of noise sources and propagation paths have been mainly carried out. For example, the methods for noise sources use a filter, and methods for propagation paths use shield wiring, ferrite cores, or capacitors [2,3].

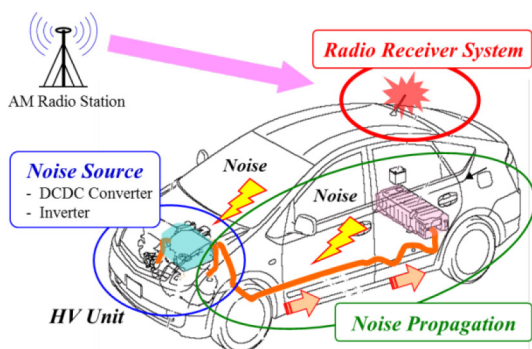


Figure 1. Electromagnetic interference to receiver system caused by HV noise

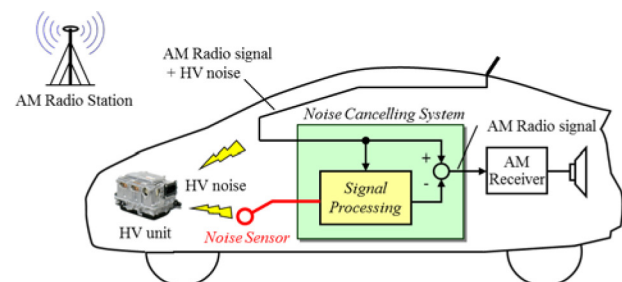


Figure 2. Noise cancelling system using noise sensor

Recently, noise suppression methods in the radio receiver have also been proposed [4,5]. One of the methods is shown in Fig. 2 [4]. A noise signal is obtained by a sensor arranged near the power control unit, and then the noise signal is subtracted by signal processing from the AM radio signal containing the HV noise. The method requires a noise sensor, and a sufficient noise suppressing effect is not obtained when the target noise cannot be accurately detected. Therefore, it is necessary to select the sensor location where only the target noise can be detected. And it is also necessary to shield the cable which connects the signal processing circuit with the radio antenna to prevent the interference from other signals.

Alternatively, a method that utilizes the periodicity of HV noise has been proposed [5]. This method cancels the noise by using the correlation between the noise in the frequency at which no radio. **Documents**
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signal exists and the noise superimposed on the radio signal [5]. In this method, the suppression effect deteriorates extremely when the periodicity of the noise is changed even slightly.

In this paper, a new noise suppression method using the digital signal processing in the AM radio receiver is proposed. This method does not require a noise sensor and the periodicity of HV noise. Instead, a receiving AM radio signal containing HV noise is resolved into the in-phase component and the quadrature component of a carrier by quadrature demodulation. As a result, the radio signal and the HV noise appear in the in-phase component, and only the noise appears in the quadrature component. The noise superimposed on the AM radio signal is eliminated by using the noise in the quadrature component.

First, we describe the quadrature demodulation of an AM radio signal containing HV noise. Next, a noise cancelling method that uses the noise in the quadrature component is proposed. Finally, we construct a prototype of the radio receiver system and demonstrate that the system can reduce the DC-DC converter noise superimposed on the AM radio signal by more than 20 dB.

QUADRATURE DEMODULATION OF AM RADIO SIGNAL SUPERIMPOSED WITH HV NOISE

In this section, quadrature demodulation of an AM radio signal superimposed with HV noise is described by using Fig. 3 and Fig. 4. The AM radio signal is generated by varying the amplitude of the carrier signal in accordance with the audio signal $a(t)$, as shown in Fig. 4(a). Thus, the phase of the AM radio signal is always equal to that of the carrier. In other words, the AM radio signal has only the in-phase component to the carrier.

First, quadrature demodulation of the AM radio signal is illustrated. Fig. 3 shows a block diagram of quadrature demodulation. The received signal $r(t)$ is multiplied by two sinusoidal signals with frequencies equal to the carrier frequency but with phases different by 90 degrees, i.e., in-phase carrier and quadrature carrier. Then, low-frequency components are extracted by low-pass filtering. The signals obtained by multiplying the in-phase carrier and the quadrature carrier are called the in-phase component and the quadrature component, respectively. The AM radio signal $r_{AM}(t)$ can be expressed as

$$r_{AM}(t) = a(t)\cos\omega_c t \quad (1)$$

where $a(t)$ and ω_c denote the audio signal and the carrier frequency of AM radio, respectively. Hence, the in-phase component and the quadrature component of the AM radio signal are calculated as follows.

$$i_{AM}(t) = \text{LPF}[r_{AM}(t)\cos\omega_c t] = a(t) \quad (2)$$

$$q_{AM}(t) = \text{LPF}[r(t)\cos(\omega_c t + \pi/2)] = 0 \quad (3)$$

where $\text{LPF}[*]$ denotes low-pass filtering. As shown by Eq. (2) and Eq. (3), the in-phase component $i_{AM}(t)$ includes only the audio signal $a(t)$, and the quadrature component $q_{AM}(t)$ includes no signal. The waveforms are shown in the center of Fig. 4(a). The Fourier transform of these components can be written as

$$I_{AM}(\omega) = A(\omega) \quad (4)$$

$$Q_{AM}(\omega) = 0 \quad (5)$$

where $A(\omega)$ denotes the Fourier transform of $a(t)$. The frequency spectrums of the components are shown on the right side of Fig. 4(a). The carrier signal, the upper side band (USB) and the lower side band (LSB), which are the components of the AM radio signal, appear in the in-phase component. In contrast, no signal appears in the quadrature component.

Next, quadrature demodulation of the HV noise is illustrated. HV noise generated by the DC-DC converter and the inverter is composed of a number of sinusoidal waves. Because HV noise is generally asynchronous to the carrier, the frequency of the HV noise does not coincide with that of the carrier. HV noise signal $n_{HV}(t)$, which is mixed in the receiver channel, can be expressed as

$$n_{HV}(t) = \rho \cos(\omega_c + \Delta\omega)t \quad (6)$$

where ρ denotes the amplitude of HV noise, and $\Delta\omega$ denotes the frequency difference between the carrier and the HV noise. Hence, the in-phase component and the quadrature component of the HV noise are calculated as follows.

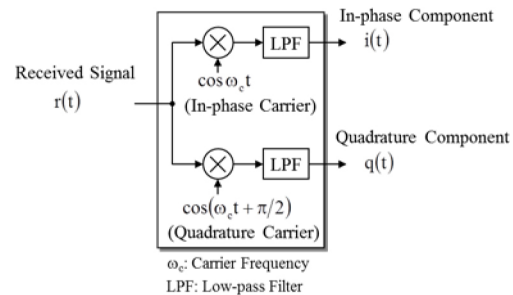


Figure 3. Block diagram of the quadrature demodulation