POS2-46

Inverter Noise Suppression System Using PI Algorithm

#Taketo Matsuoka [1] and Mitoshi Fujimoto [1] and Toshikazu Hori [1]
[1] Graduate School of Engineering, University of Fukui
3-9-1, Bunkyo, Fukui, 910-8507 Japan, matsuoka@wireless.fuis.u-fukui.ac.jp

1. Introduction

Electric vehicles and hybrid vehicles have been popularized in recent years. In such a vehicle, a PCU (Power Control Unit) which controls the power of electric motors is mounted. An inverter circuit which converts a direct current stored in the battery into an alternating current is included in the PCU. Due to the noise from the inverter, communication quality utilized on the vehicles is deteriorated.

This paper, proposes a novel noise reduction system composed of a noise sensor and an adaptive filter which is controlled based on PI(Power Inversion) algorithm[1]. Numerical results show the noise reduction effects by the proposed system.

2. Interference to AM Radio Reception by Inverter Noise

An AM radio receiver, a FM radio receiver, a Terrestrial digital TV receiver, a mobile phone, a GPS, etc. are installed as communication facilities in a vehicle. The frequency bands for each communication facility in Japan are shown in Table 1. [2]

Table 1: Frequency Allocation in Japan

AM Radio Broadcasting	526~1606[kHz]
FM Radio Broadcasting	76~90[MHz]
Digital Television Broadcasting	470~770[MHz]
Mobile phone	800~ [MHz]
GPS	1.5[GHz]

Especially, the sound quality of the AM radio tends to be deteriorated by the inverter noise, because a low frequency band is utilized for AM radio broadcasting. An example of the spectrum observed on an actual vehicle is shown in Fig. 1. Not only AM radio signals but also several inverter noises are observed in the AM radio band. Since the frequency of the inverter noise changes with the load of the PCU, it is impossible to take out only AM radio signal using an usual band pass filter.

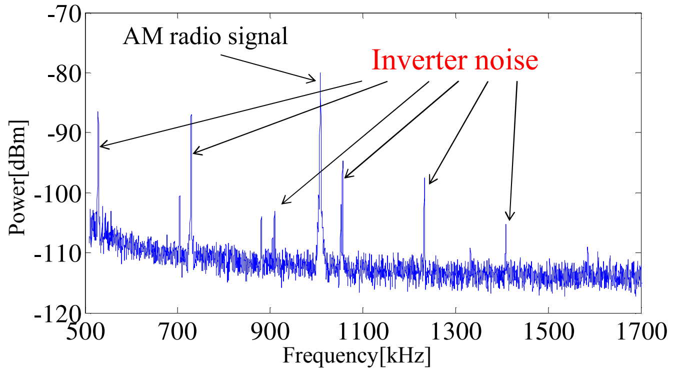

Figure 1: The Spectrum Observed on an Actual Vehicle

3. Novel Noise Suppression System Composed of Noise Sensor and Tapped Delay Line.

3.1 Acquisition of Inverter Noise using Noise Sensor

The usual active noise canceller reduces the undesired signal using the original received signal. Since both the inverter noise and the radio signal are included in the signal received by the AM radio antenna, there is a possibility that the AM radio signal is also suppressed by the canceler.

Then, only an inverter noise is acquired by the noise sensor which is installed in PCU as shown in Fig. 2. The inverter noise received by the AM radio antenna is reduced using the acquired signal.

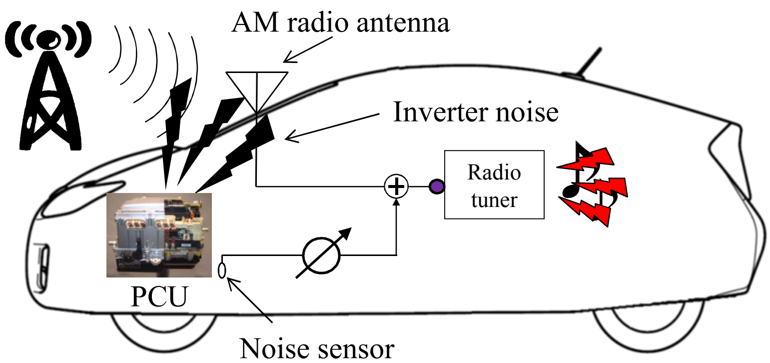

Figure 2: Acquisition of Inverter Noise by Noise Sensor

3.2 Configuration of Proposed Noise Suppression System

In order to remove the inverter noise, the inverter noise acquired by noise sensor adjusted so as to be the same amplitude and out of phase to the inverter noise received by the AM radio antenna. However, it is impossible to adjust the amplitude and the phase for every frequency by a single multiplier, because, the amplitude and the phase of the inverter noise depend on the antenna characteristics and the frequency characteristics of the cable for frequency by frequency.

Figure 3 shows the configuration of proposed system. In the system, the amplitude and the phase adjustments in frequency by frequency are enabled by introducing a tapped delay line.

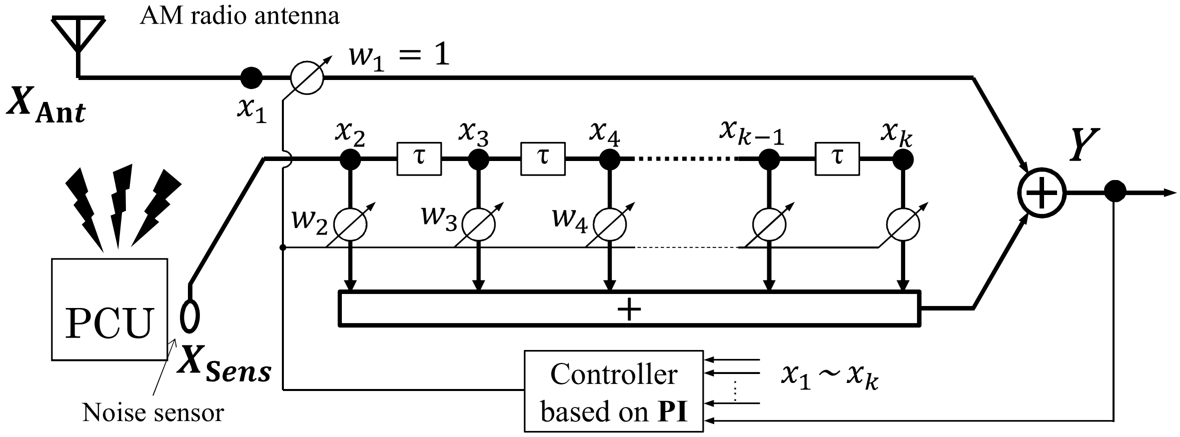

Figure 3: Configuration of Noise Suppression System with Tapped Delay Line

3.3 Determination of Optimum Wight Coefficients based on PI Algorithm

In the proposed system, weight coefficients for multipliers are based on the PI algorithm. Namely, the weight coefficients in Fig. 3 are determined so as to minimize the power of the output signal " $\boldsymbol{Y}$ ". As the result, the inverter noises received by the sensor and AM radio antenna are cancelled each other [1].

Equation (1) shows the input vector for PI algorithm. The first element of the input vector x_1 is the received signal "$\boldsymbol{X_{Ant}}$" by the AM radio antenna. Other elements are made from the output of the noise sensor "$\boldsymbol{X_{Sens}}$". Namely, $x_2 \sim x_k$ are the outputs of the tapped delay line as shown in the Fig. 3.

$$\boldsymbol{X}(t) = [x_1 \quad x_2 \quad \cdots \quad x_k]^{\mathrm{T}} \tag{1}$$

Here, superscript T expresses a transposition of a matrix. Weight coefficient vector "$\boldsymbol{W}_{opt}$" is determined based on PI algorithm utilizing the signal of Eq. (1). Weight coefficient vector "$\boldsymbol{W}_{opt}$" is indicated as shown in the Eq. (2).

$$\boldsymbol{W}_{opt} = [w_1 \quad w_2 \quad \cdots \quad w_k]^{\mathrm{T}} = R_{xx}^{-1} \cdot \boldsymbol{C} \tag{2}$$

Here, "R_{xx}" is the correlation matrix of the input signal vector "$\boldsymbol{X(t)}$". "$\boldsymbol{C}$" is called constraining vector and indicated as shown in the Eq. (3).

$$\boldsymbol{C} = [1 \quad 0 \quad \cdots \quad 0]^{\mathrm{T}} \tag{3}$$

The correlation matrix "R_{xx}" is indicated as shown in Eq. (4)

$$R_{xx} = E[\boldsymbol{X}(t)\boldsymbol{X}^{\mathrm{H}}(t)] \tag{4}$$

utilizing the input signal vector "$\boldsymbol{X(t)}$" [3]. "$E[\,]$" indicates the expectation. Superscript H expresses a complex conjugate transposition of a matrix. Furthermore, "$\boldsymbol{W}_{opt}$" is normalized by "w_1" as shown in the Eq. (5).

$$\boldsymbol{W}_{opt} = \frac{\boldsymbol{W}_{opt}}{w_1} = \frac{[w_1 \quad w_2 \quad \cdots \quad w_k]^{\mathrm{T}}}{w_1} \tag{5}$$

Therefore, the AM radio signal is protected even if the output power is minimized.

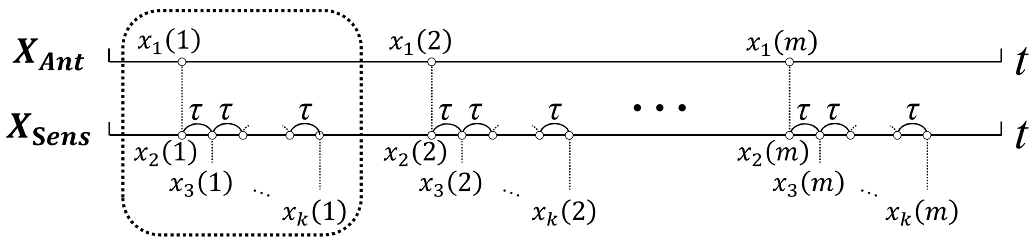

Figure 4: Timing of Sampling

In the portion enclosed with the dotted line in Fig. 4, the first element of the input vector x_1 is received signal by the AM radio antenna "$\boldsymbol{X_{Ant}}$(t)" in time t, the second element x_2 is the input signal of the noise sensor "$\boldsymbol{X_{Sens}}$(t)" at the same time. Next, the third element x_3 is the output of the noise sensor "$\boldsymbol{X_{Sens}}(t+\tau)$" after τ second which is the tap interval. The fourth element x_4 is the output of the noise sensor "$\boldsymbol{X_{Sens}}(t+2\tau)$" after to 2τ second. The same operations are repeated *k* times. The above operations correspond to one snapshot to constitute the input vector "$\boldsymbol{X}(t)$" in Eq. (1). In order to calculate the "R_{xx}", the snapshot is repeated *m* times.

4. Noise Suppression Effect of Proposal System

In actual environment, plural inverter noises interfere to the communication system. Therefore, it is expected that many taps are required to obtain enough performance. The relationship between the number of taps and output SINR is shown in Fig. 5. The parameter is a number of inverter noises. Here, the power ratio of the inverter noise and thermal noise at sensor output (input INR_{Sens}) is 30dB. A large value of input INR_{Sens} corresponds to the excellent sensor sensitivity. It can be found from Fig. 5 that many taps are required as many inverter noises interfere, and the optimal number of taps exists.

Let me define "k_{opt}" as the number of taps which provides maximum SINR. The relationship between the number of the inverter noises and the k_{opt} is shown in Fig. 6. Figure 6 indicates that inverter noises can be suppressed well with a small number of taps if the sensitivity of a sensor is excellent.

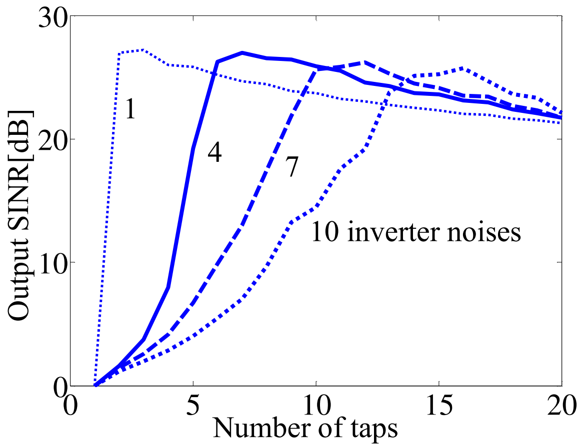

Figure 5: Effect of Proposal System

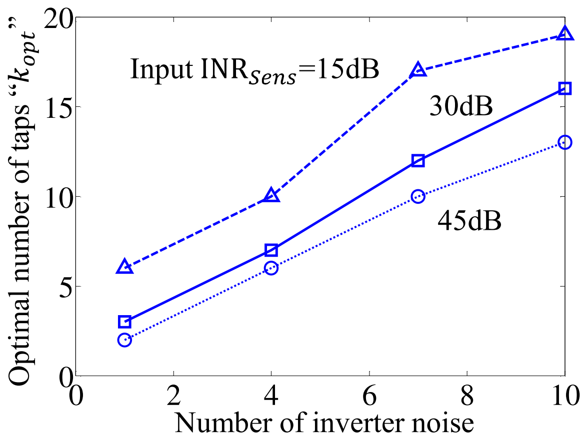

Figure 6: Optimal Number of Taps

5. Conclusions

A novel noise suppression system composed of a noise sensor and an adaptive filter based on PI(Power Inversion) algorithm was proposed.

It was clarified that the optimal number of taps which is required to obtain enough performance depended on the number of the inverter noises. Moreover it was also shown that the inverter noises could be suppressed with a small number of taps if the sensitivity of a sensor was excellent.

Acknowledgments

This work was supported by Adaptable and Seamless Technology Transfer Program through Target-driven R&D, Japan Science and Technology Agency.

References

[1] R.T. Compton, Jr., "The power inversion adaptive array: concepts and performance," IEEE Trans. Aerosp. Electron. Syst., vol.AES-15, No.6, pp.803-814, Nov. 1979.

[2] "Frequency allocation in Japan" Ministry of Internal Affairs and Communications, http://www.tele.soumu.go.jp/

[3] N. Kikuma, "Adaptive Signal Processing with Array Antenna," Science and Technology Publishing Company, Inc., 1998 (in Japanese).