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Design of Digital Robust Controller for a Class-D Amplifier Using A2DOF

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Abstract

In recent years, it is desired that the bandwidth of a class-D amplifier is widened using sampling frequencies as low as possible. For example, it is expected in the application of the power supply of a low frequency immunity test, or an audio power amplifier, or the power amplifier of vibration generator. In this paper, it is shown that the bandwidth of the class-D amplifier can be widened to 20[kHz] by an A2DOF (Approximate 2-Degree-Of-Freedom) digital controller with 500[kHz] sampling frequencies. The controller is implemented by a DSP (digital signal processor). It is shown from experiments that 20[kHz] bandwidth can be maintained even if load changes.

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Keywords: class-D amplifier; digital robust control; A2DOF; DSP

1. Introduction

In recent years, various kincds of the application of a class-D amplifier is considered. For example, the applications are the power supply of a low frequency immunity test, or the audio power amplifier, or the power amplifier of vibration generator. In these applications, it is expected that the bandwidth of the class-D amplifier is

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widened using sampling frequencies as low as possible from the limit implementing digital controllers in micro-processors. In the reference [1-3], sampling frequencies more than sevral MHz are used. However, good control algorithms can not be realized in usual micro-prosessors with this sampling frequency. The authors have already proposed the method [4] that is suitable for designing a controller of PWM power amplifiers. This method is using an A2DOF (Approximate 2-Degree-Of-Freedom) system and the performance is better than the method [5] but the bandwidth is not wide enough. It is desired to widen the bandwidth for various applications. In this paper, it is shown that the bandwidth of the class-D amplifier can be widened to 20[kHz] by the A2DOF digital controller with 500[kHz] sampling frequencies. This proposed digital controller is actually realized by a DSP (Digital Signal Processor). It is shown from experiments that 20[kHz] bandwidth can be maintained even if load changes.

2. Class-D amplifier

A class-D amplifier of Fig.1 has been made. A full-bridge chopper circuit is used for power amplification, and the DC power-supply voltage E is 30 [V]. The values of LC filter are L_0 = 44 [μH] and C_0 = 0.235 [μF].

If the frequency of a control input u is smaller than that of a carrier wave , the state equation of the class-D amplifier of Fig. 1 is derived from the state equalizing method as follows:

$$\begin{cases}\dot{x}(t) = A_c x(t) + B_c u(t) \\ y = Cx(t)\end{cases} \quad x(t) = \begin{bmatrix} e_0(t) \\ i(t) \end{bmatrix} \quad A_c = \begin{bmatrix} -\frac{1}{C_0 R_L} & \frac{1}{C_0} \\ \frac{1}{L_0} & -\frac{R_0}{L_0} \end{bmatrix} \quad B_c = \begin{bmatrix} 0 \\ \frac{K_p}{L_0} \end{bmatrix} \tag{1}$$

$$y(t) = e_0(t) \qquad u(t) = e_i(t) \qquad C = [1 \quad 0]$$

Here K_p is the steady-state gain, and is 0.002. R_0 is the total resistance consisting of coil and ON resistance of FET, etc., and is about 2 [Ω]. The delay time depending on AD conversion time and DSP computing time is considered to be an input dead time existing in the controlled object. Moreover a delay element $1/z$ is added to the input of the controlled object for replacing the current feedback with the input feedback and the output feedback.

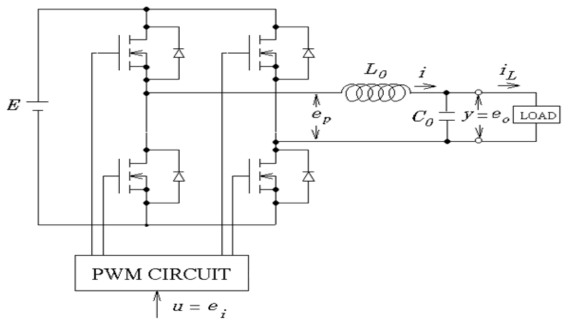

Fig. 1. Class-D power amplifier

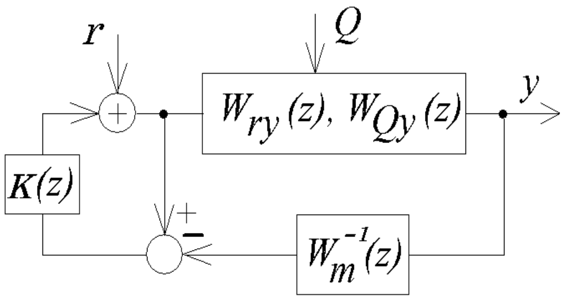

Fig. 2. Robust control system

Then the state equation of the system considering these two delay elements is expressed as follows:

$$\begin{cases} x_{dw}(k+1) = A_{dw} x_{dw}(k) + B_{dw} v(k) \\ y(k) = C_{dw} x_{dw}(k) \end{cases} \tag{2}$$

$$x_d(k) = \begin{bmatrix} x(k) \\ \xi_1(k) \end{bmatrix} \; x_{dw} = \begin{bmatrix} x_d(k) \\ \xi_2(k) \end{bmatrix} \; A_{dw} = \begin{bmatrix} A_d & B_d \\ 0 & 0 \end{bmatrix} \quad B_{dw}(k) = \begin{bmatrix} 0 \\ 1 \end{bmatrix} A_d = \begin{bmatrix} e^{AcT} & e^{Ac(T-L_d)} \int_0^{Ld} e^{Ac\tau} B_c d\tau \\ 0 & 0 \end{bmatrix}$$

$$B_d = \begin{bmatrix} \int_0^{T-Ld} e^{Ac\tau} B_c d\tau \\ 1 \end{bmatrix} \qquad \xi_1(k) = u(k) \quad C_d = [C \quad 0] \quad C_{dw} = [C_d \quad 0]$$

Load changes and DC power supply changes are considered as parameter changes of Eq. (1). The parameter changes are transformed to equivalent disturbance input to eq. (1). Therefore, in order to suppress the influence of