Effects of the Number of Levels in Multi-Levels PWM on the Signal Quality

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Abstract

This article presents simulation results of multi-levels PWM system. The experiment varies the number of the levels including 2, 3, 5, 7, 9, and 11 levels each at 4 different carrier frequencies i.e. 150 kHz, 200 kHz, 250 kHz, and 300 kHz. The suitable level number and carrier frequency is then found by comparing the quality of the output signal of the system at the various settings. From the simulation results, the optimal parameter is 5 multi-levels PWM at 200 kHz carrier frequency.

Keywords: Class-D Amplifier, Multi-level PWM

Introduction

In the past, amplifying the signal from the digital source, such as compact disc player, used analog amplifier. This meant digital signal was converted to analog signal by using digital to analog converter (DAC). Then, the signal was sent to the process of analog amplifier. The analog circuit had to be connected to Pre-Amp and amplifier as shown in Figure 1. Analog amplifier had several disadvantages. For example, there was a chance for interference intruded into the circuit and affected the noise quality. Furthermore, the original amplifier, such as Class-A Amplifier and Class-AB Amplifier had low efficiency. They were not suitable for the source with limited power such as in the car.

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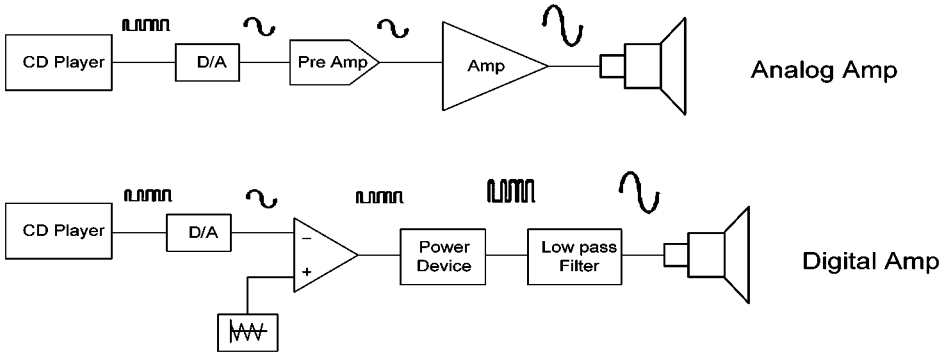

Figure 1. The comparison of the structure of analog and digital amplifiers.

According to such reasons, the digital amplifier or Class-D Amplifier was developed. The process to amplify digital signal consisted of converted digital signal to analog. The signal was modulated with the carrier. As shown in Figure 1, Unipolar Pulse Width Modulation (UPWM) was an output. It was fed to Class-D Amplifier in order to amplify PWM. The signal was passed through the low-pass filter circuit. Finally, the signal was sent to the speaker. (Goldberg and Sandler, 1994) In the present, Class-D Amplifier was popular because it is highly efficient, with the small size and light weight. (Flors and Mourjopoulos, 1998).

Converting digital signal to pulse width modulation reduced the problem with the interference from connecting the signal. Normally, the signal was the Uniform Pulse Width Modulation. There were some parts of the pulse width that were really narrow. They were very hard to replicate. Currently, a lot of people are interested in solving the problem using many different methods.

One method that got the attention from other researchers was to use Multi-level Pulse Width Modulation instead of Uniform Pulse Width Modulation. (Antuneso et al., 2004) Multi-level Pulse Width Modulation had wider pulse width than the one from Uniform Pulse Width Modulation. Hence, it was easier to create Multi-level Pulse Width Modulation as shown in Figure 2. Multi-level PWM can reduce the Total Harmonic Distortion to be lower than using UPWM. (Antuneso, Silvas and Fernaopires, 2004)

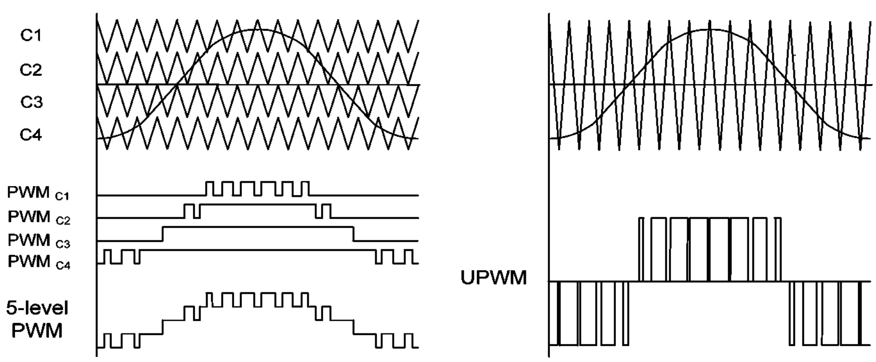

Figure 2. Comparison between Multi-Level PWM and UPWM
(A) Multi-level Pulse Width Modulation (B) Uniform Pulse Width Modulation

This article recommended changing the parameter between the levels in PWM signal and the number of the carrier. The purpose was to analyze the suitability in designing the number of levels in PWM signal and the carrier frequency signal. This was to reduce the budget and the complexity in the design on the amplifier as shown in Figure 3.

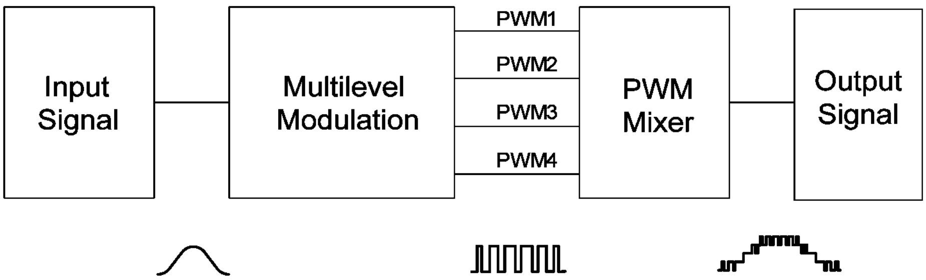

Figure 3. Structure of Multi-Level PWM system presented in this research

Principles of Multi-Levels PWM signal generator

Principles of Multi-Levels PWM signal generator were the modulation between the input signal and several carrier signals. Generally, the size of the reference signal was set to 1. 5-Levels PWM with 4 carrier signals had the wave size equaled to 1/2 as shown in Figure 2(A). The relationship between the carrier signal and the number of the levels in Multi-Levels PWM can be represented in Equation (1).

$$n_{carrier} = n_{level} - 1 \qquad (1)$$

When $n_{carrier}$ is the number of carrier signal

n_{level} is the number of levels of output pressure

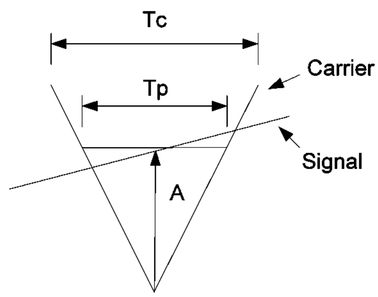

Figure 4. Relationship between the pulse width and modulation signal

The relationship between the pulse width and the height of the input signal for Multi-Levels PWM was shown in Figure 4. It can be written in an equation as shown in Equation (2).

$$A = \frac{T_P}{T_C} \qquad ;0 \le A \le 1 \qquad (2)$$

When A is the height of input signal

T_P is the pulse width of the output signal

T_C is the period of the carrier signal

To create Multi-Levels PWM signal, n_{level}-1 carrier signal was used as shown in Figure 2(A). To create 5-Levels PWM signal, 4 carrier signals must be used. Also, the additional signal was required to combine the signals. This additional signal came from the modulation of input signal and the constants. For 5-Levels PWM signal, 3 constants were required as shown in Figure 5. The relationship can be written in equations as shown in Equation (3) and (4).

$$A_1 = \begin{cases} 1 & ; signal \geq 0 \\ 0 & ; signal \pi 0 \end{cases} \qquad (3)$$

$$A_2 = \begin{cases} 1 & ; |signal| \geq \frac{1}{2} \\ 0 & ; |signal| \pi \frac{1}{2} \end{cases} \qquad (4)$$

The size of the input signal used to calculate the pulse width of 5-Levels PWM signal is shown in equation (5). It can be noticed that there were 2 constants multiplied in order to maintain the value per one unit. This was because the height of the carrier signal in each period was equaled to ½.

$$A = \begin{cases} 2(m\sin(\omega t) - \frac{1}{2}) & ; \frac{1}{2} \leq m\sin(\omega t) \leq 1 \\ 2(m\sin(\omega t)) & ; 0 \leq m\sin(\omega t) \leq \frac{1}{2} \end{cases} \qquad (5)$$

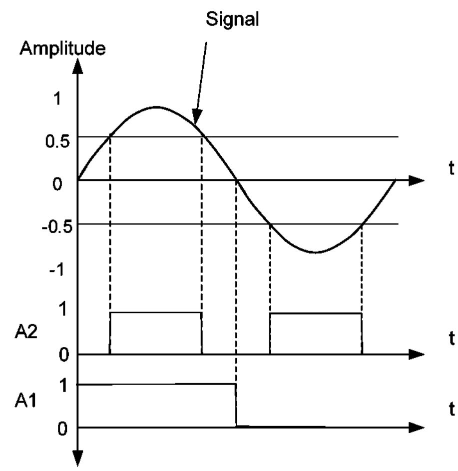

Figure 5. Signal A1 and A2 used to combine Multi-Levels PWM signal.

Experimental Design

In this article, simulink/MATLAB program was used to simulate Multi-Levels PWM. The example of the prototype using simulink/MATLAB was shown in Figure 6. In the simulation, the number of levels was adjusted to 2, 3, 5, 7, 9, and 11. The carrier frequency was at 150 kHz, 200 kHz, 250 kHz, and 300 kHz, respectively. The total number of the prototype was 24. The frequency of the input signal used in the simulation was 1 kHz.

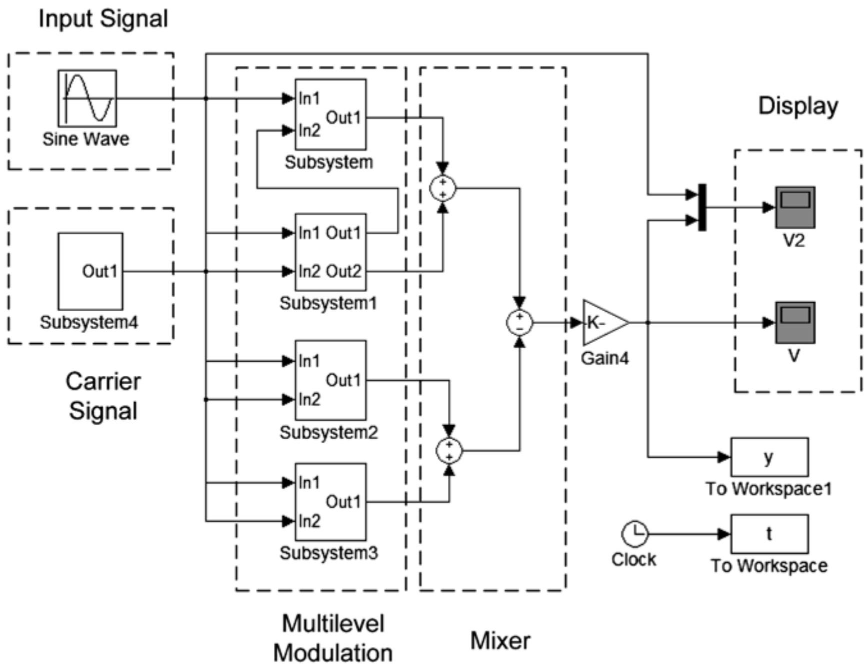

Figure 6. Example of Multi-Levels PWM signal conversion using simulink/MATLAB

The test signal was sent to Multi-Levels PWM signal conversion process. The number of carrier signal was calculated as shown in Equation (1). It began with 2-Levels PWM prototype. In each level, the carrier frequency was adjusted to 150 kHz, 200 kHz, 250 kHz, and 300 kHz.

The parameter and step time to simulate the simulink/MATLAB condition were set to align with 7 bits carrier signal. The value of step time is as shown in Equation (6).

$$Step \quad time = f_{carrier} \times 4 \times (2^7 - 1) \qquad (6)$$

The simulation of 24 prototypes was performed. The quality of output signal was measured by using THD (Total Harmonic Distortion). The results were compared in order to find the suitable parameter.

Experimental Result

The experimental result was shown in table 1. %THD of output signals from Multi-Levels PWM system were shown. They were 6 different levels. There were 4 frequencies of the carrier signal for each level. %THD of output signals were displayed in graph as shown in Figure 7.

Table 1. %THD from the simulation to create Multi-Levels PWM signal at different parameters.

Level	Carrier Frequency (kHz)	%THD
2	150	117.5654
	200	109.0550
	250	109.0579
	300	105.9887
3	150	26.2071
	200	20.6436
	250	19.2434
	300	15.0215
5	150	14.4457
	200	9.3868
	250	8.9919
	300	6.8034
7	150	8.7358
	200	6.4672
	250	6.4742
	300	4.6183
9	150	6.5762
	200	5.1100
	250	5.1635
	300	3.5925
11	150	5.3231
	200	4.1399
	250	4.1635
	300	2.9093

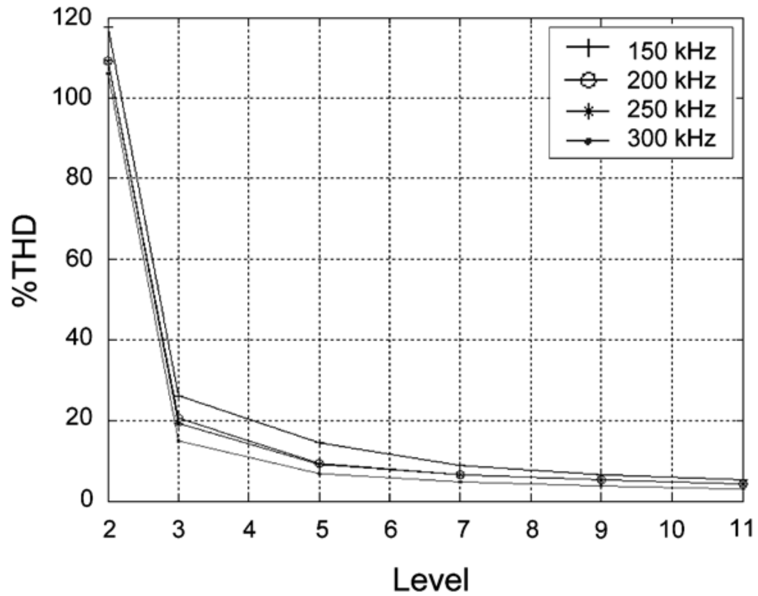

Figure 7. %THD from the simulation to create Multi-Levels PWM signal at different parameters

According to the test result, it was revealed that, at every level of Multi-Levels PWM, %THD of the output signal from the system with higher carrier frequency was mostly lower. The number of levels in Multi-Levels PWM higher than 5 levels, %THD of the output signal from the system with carrier frequency equaled to 250 kHz and the one from system with carrier frequency equaled to 300 kHz was not different.

When studied the test result comparing with the number of levels in Multi-Levels PWM, it was revealed that %THD of the output signal at every carrier frequency was likely to be reduced when the number of levels in Multi-Levels PWM was increased. However, the difference in %THD of the output signal at the number of levels in Multi-Levels PWM higher than 5 had much less the ratio, compared with %THD of the output signal at the number of levels in Multi-Levels PWM with all carrier frequency.

Conclusion & Discussion

This article presented the quality comparison of the output signal from Multi-Levels PWM at various levels, which were 2, 3, 5, 7, 9, and 11; and various carrier frequencies of 150 kHz, 200 kHz, 250 kHz, and 300 kHz, respectively. The signal quality was measured by measuring %THD of the output signal.

The test result revealed %THD of the output signal was likely to be reduced when the number of levels in Multi-Levels PWM was higher and when the carrier frequency was higher. However, it was noticed that %THD of the output signal decreased when the number of levels in Multi-Levels PWM was higher than 5. The %THD Difference (Δ%THD) in the output signal at the carrier frequency of 200 kHz and 250 kHz was between 0.0070%-0.3949%. There was only a slight difference when comparing with 2-Levels and 3-Levels PWM, which was 88.41% difference at the carrier frequency of 200 kHz and 89.81 % difference at the carrier frequency of 250 kHz. 5-Levels PWM with carrier frequency of 200 kHz and 250 kHz resulted in 9.3868%THD and 8.9919 %THD, respectively, when comparing to the product in the market. For example, TDA7294 (Dmos Audio Amplifier) had %THD equaled to 10%. (TDA7294, 2003) It was found that the value was less. When considering the price and the complexity of the system, it was found that the optimized carrier frequency was 200 kHz and the optimized number of levels in Multi-Levels PWM was 5-Levels.

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