Audio Signal Deterioration Caused by Propagation Noise between Audio Equipment (2nd report)

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Abstract. Sound quality of music playback may be deteriorated due to various complex factors such as power supply state of the audio equipment. Therefore, in our previous study, we partly confirmed the mechanism that the power supply states affected alternative-current (AC)-potential difference and propagation noise between the equipment, which influenced audio-signal intermodulation distortion (IMD) on one of personal-computer (PC)-audio system. However, the research was insufficient in the number of measured audio equipment and measuring setup. In this study, we increased the model of digital-to-analog converter (DAC) and audio amplifier used for measurement and improved the measurement method to reduce the influence of measuring equipment. We measured ground AC potential, propagation noise, and the analog audio signal output of the amplifier. Their measurements were done in changing combination of audio equipment and each power supply states to analyze the relationship among these three domains. As a result, it is found that each domain depended on the model, combination, and power supply states of each audio equipment. There is a strong positive correlation between the ground AC potential and the propagation noise. There is also a positive correlation between the propagation noise and the audio-signal IMD in some combination of audio equipment.

1. Introduction
In recent years, personal-computer (PC)-audio systems that use the PC and digital-to-converters (DAC) have become popular, and digital-audio technologies are now in progress to improve high-quality-sound playback. However, in an actual music playback environment using audio equipment, sound quality of music playback may be deteriorated due to various complex and interrelated factors, such as the state and polarity of each alternative current (AC) power supply in each equipment [1],[2], the operating state of the PC [3], and so on. In these previous study [1]~[3], focusing on the sound quality deterioration due to jitter, and the mechanism of generation has not been elucidated. Even today, it is necessary to tune audio equipment and systems subjectively based on the knowledge and experience of the acoustic technicians in order to play with best performance of the audio equipment.

We considered one reason of remaining such troublesome situation is that the mechanisms leading to the degradation of sound quality have yet to be elucidated. In addition, another reason is that acoustic-measurement methods and objective evaluation criteria to describe sound-quality deterioration have not been specified. To address these situation, we considered one factor of sound-quality deterioration mechanism as AC potential differences between audio equipment caused by the power supply in each piece of equipment, and the noise loop due to indirect coupling and the resulting propagation of
electromagnetic noise between parts of the equipment. These propagation noise can modify the analog audio output signal and thereby perturb the resulting subjective auditory sensation [4]. Therefore, in our previous study, we measured the ground AC potential at the USB ground of the PC using a digital multimeter, the propagation noise current at the USB ground line between the PC and the DAC using an oscilloscope with a differential probe, and the analog audio signal at the loudspeaker output of the amplifier using an audio analyzer, as a function of the type and polarity of each power supply on each equipment on one of PC-audio system [5]. This audio system for the measurement consists of PC, universal-serial-bus (USB) connected DAC, and audio amplifier for the purpose of verifying the focused the sound-quality deterioration mechanism. The result of the previous study showed that the amplitude and shape of the propagation-noise waveforms on the USB ground between the PC and the DAC differed and depended on PC-power supply state, i.e., battery powered or AC power supply (AC adapter) powered. In particular, the 50 Hz noise component (hum noise) from the AC power supply was remarkable. Furthermore, power supply state affected the 50 Hz component and its harmonics distortion in the audio signal output of one amplifier. In addition, power supply state also affected the IMD components around the fundamental wave of the playback single sine wave. There was a positive correlation between the ground AC potential, the propagation noise, and the audio-signal IMD. However, the previous research was insufficient in the number of measured audio equipment and measurement setup, because the targeted audio equipment used in the previous measurement was only one set. In addition, there was a problem that the results might be affected by a model of measurement equipment.

Therefore, in this study, we measured by changing combination of audio equipment consisted of 3 models of DAC and 6 models of amplifier and each power supply states and we analyzed among those 3 domains in order to elucidate that sound deterioration mechanism more detail. In this study, the measurement was done by improved measuring method to reduce the influence of measuring equipment.

2. Measurement setup and conditions

Figure 1 shows the setup for measuring the ground AC potential, the propagation noise, and the audio signal. This system can accommodate different types and polarity of power supplies for each device. In our previous study, one model of DAC and digital amplifier was used. In this study, we measured them using 18 combinations of audio equipment consisted of 3 models of DAC (model A, B, and C) and 6 models of amplifier (3 models of digital amplifier (model a, b, and c) and 3 model of analog amplifier (model d, e, and f)).

The AC potential of the equipment is the potential difference between the ground of the USB output of the PC (Apple, MacBook air) for playback and the laboratory ground. This was measured by a digital multimeter (Tektronix, DMM4040) in AC voltage mode with PC for playback, DAC, and amplifier are all connected and powered on. The current related to the propagation noise was measured using a Tektronix oscilloscope (DPO7254, bandwidth 2.5 GHz) equipped with a differential probe (Tektronix,
TDP1000, bandwidth 1 GHz) by a resistor (4.7 Ω) inserted into the ground line of the USB connecting the PC and the DAC. Its resistance value was set at balanced value considered of sensitivity and insertion influence. The oscilloscope operated at 1 MHz sampling frequency, 1 MSample record length, and 1 second measurement duration.

These measurements of the ground AC potential and the propagation noise were measured without connecting an audio analyzer in order to avoid influences by measuring instrument on measured results. The reason is that an audio analyzer makes another indirect connection such as ground loop and causes some influences on measured results because an audio analyzer is active device that has a power supply. In contrast, connecting loudspeakers to the output of the amplifier does not make influences on measured results because loudspeakers are passive device that have not a power supply. These influences were experimentally confirmed in our experiment.

The analog audio signal was measured at the loudspeaker output of the amplifier using an audio analyzer (Audio Precision, APx525) and battery powered notebook-PC (Sony, VAIO type-Z) only for control the audio analyzer. This measurement applied a fast Fourier transform (FFT) to analyze the audio spectrum. This was measured 5 times for each measurement condition, and the average value was calculated. A 10.011 kHz sine wave (WAV file format, 44.1 kHz sampling frequency, 24-bit quantization) was used as a test signal for the measurement. The amplitude of playback sine wave is set to 1.0 Vrms by setting the gain of each amplifier. We used music-player-software PlayPcmWin in WASAPI push mode on Microsoft Windows 8.1 to play this WAV file. The specifications of the FFT analysis of the audio spectrum was 48 kHz sampling frequency, 192 kSample record length, and 4 seconds measurement duration. The measurements were done after each device warmed up for over two hours.

Table 1 lists the combinations of power-supply states that can affect the AC potential of the equipment and the noise loop. There are 3 kinds of power supply states of the PC for playback and 2 power supply state of the DAC and amplifier, i.e., there are total 12 combinations of power supply states. This is mainly focused on the influence due to noise and noise-loop change derived from the power supply. The output of the DAC and the amplifier were connected only the right channel of stereo 2 channels.

Japanese commercial AC 100 V power and audio-equipment-power source is normally 2 poles, i.e., Line and Neutral. We defined the original polarity of the power supply as “Polarity A” and the opposite polarity, i.e., the line and neutral were reversed, as “Polarity B”. The line and the neutral were reversed also on an audio equipment which had 3 poles AC inlet. The commercial AC-power-line frequency in eastern Japan was 50 Hz. The audio analyzer was driven by a regulated AC power supply at 60 Hz in order to distinguish whether the frequency components of the measured spectrum of the audio signal was caused by the interaction with audio analyzer or only by the interaction within the audio equipment.

Table 1. Experimental condition about the combination of the power state of each equipment.

| Equipment | PC | DAC | Amplifier |
|-----------|----|-----|-----------|
| Power supply state | • Internal battery | • AC Adapter (Polarity A) | • AC Adapter (Polarity A) |
| | • AC Adapter (Polarity A) | • AC Adapter (Polarity B) | • AC Adapter (Polarity B) |

3. Measurement results and consideration

3.1. Audio equipment’s model dependency of the relationship between the AC potential and the propagation noise

Figure 2 shows the relationship between the ground AC potential and the amplitude of the propagation noise amplitude on the USB ground. The 216 measurement results for all combinations of the 12 power supply states are shown in Figure 2. The horizontal axis shows the AC potential, and the vertical axis shows the amplitude of the propagation noise. The measurement results are divided into 6 groups according to the power-supply states of the PC and DAC, and amplifier. The results show that the AC potential and the propagation noise amplitude are strongly correlated. The correlation coefficient between the AC potential and the propagation noise amplitude is 0.95. This result indicates that the AC potential is a major contributor to the propagation noise.
supply states and the 18 combinations of equipment are plotted in this figure. An approximate straight line of the 216 measurement results is also plotted in this figure. Plotted color means the combination of the equipment. The amplitude of the propagation noise is averaged peak-to-peak amplitude of the 100-point-moving-averaged waveform in order to reduce the random noise.

From figure 2, it is confirmed that the ground AC potential and the amplitude of the propagation noise varies greatly with the combinations of audio equipment and their power supply states. The relationship is a direct proportion and strong positive correlation represented by single approximate straight line.

![Figure 2. Relationship between the ground AC potential and the propagation noise amplitude on the USB ground.](image)

Figure 3 shows comparison of the propagation noise waveforms through the USB ground line in different power condition of the PC. The black line in this figure shows maximum case of the propagation noise waveform, and the gray line shows minimum case. From figure 3, it is found that 50 Hz noise components from AC power differs mainly by the power supply states.

![Figure 3. Comparison of the propagation noise waveforms through the USB ground line in different power condition of the PC.](image)

3.2. Audio equipment’s dependency of the relationship between the propagation noise and the audio signal output

Figure 4 shows the audio equipment dependency of the relationship between the propagation noise amplitude and the total value of the IMD of the audio signal output. The 216 measurement results for all combinations of the 12 power supply states and the 18 combinations of equipment are plotted in this figure. An approximate straight line of each combination of the equipment (18 combinations) is also shown in this figure. Plotted color means the combination of the equipment. The total IMD that seems to affect the auditory sensation is calculated as follows,
where $A(f)$ is the IMD amplitude at frequency $f$. In this measurement, $f_1 = 10.011$ kHz, $f_2 = 50$ Hz, and the IMD amplitude sums from 1st order to 5th order.

From figure 4, it is found that the audible IMD of the audio signal output at near frequency of the playback sound depend on the combinations of the equipment. The influences of the combination of the power supply state that has correlation with the propagation noise amplitude on the total IMD are different among the combinations of the equipment. The 5 of all 18 combinations of equipment had a positive correlation between the propagation noise amplitude and the total IMD. The other 13 combinations of equipment did not have the correlation, i.e., these equipments were not influenced by the combination, the power supply state, and propagation noise. In addition, there was no combinations of equipment with negative correlation. From this results, it seems that it is desirable to set the power supply states to less propagation noise and lower ground AC potential of audio equipment.

Figure 5 shows an example of the IMD part of FFT spectrum of the loudspeaker output of an amplifier at two power supply states in the same combination of the equipment. This figure is magnified view around the playback 10.011 kHz sine wave component. Magnified view if the IMD part of FFT spectrum of the loudspeaker output of an amplifier around the playback 10.011 kHz sine wave.

From figure 5, it is found that the occurrence of the audible IMD between the playback signal and hum noise varies greatly with dependence on the power supply states.

4. Conclusion

In this study, in order to elucidate the audio-signal deterioration mechanism, we did additional research by increasing the model of DAC and amplifier used for measurement, and improved the measurement method.

From experimental results, we found and confirmed followings;

1. The ground AC potential and the propagation noise depend on the combination of equipment and the power supply states. The audio signal IMD partly depend on the combinations of equipment and the power supply state.

2. In particular, there is a strong positive correlation between the ground AC potential and the propagation noise in all conditions of the combinations of equipment and the power supply states.
3. In some equipment and combination of equipment, there is a positive correlation between the propagation noise and audio-signal IMD.

4. The proposed sound-deterioration mechanism in our previous study that the power supply states affects the AC potential difference and the propagation noise between the equipment, and which influences the audio-signal IMD, occurs in some audio equipment and their combination. However, there are some equipment and some combinations that is not influences by the combination, the power supply state, and propagation noise.

5. The sound-quality deterioration mechanism with dependent on the combination of the equipment may be one factor that causes compatibility between audio equipment.

6. It seems that it is desirable to set the power supply states to less propagation noise and lower ground AC potential of audio equipment.

In future work, we will identify the conditions under which this sound-quality deterioration mechanism is applied, and investigate another influence of the propagation noise on audio signal.

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