The influence of non-audible plural high frequency electrical noise on the playback sound of audio equipment (2nd report)

N Kimura¹ and T Yoshida¹

¹Department of Electrical Engineering, Tokyo University of science, 6-3-1 Niijuku, Katushika-ku, Tokyo, 125-8585, Japan

E-mail: yoshida@ee.kagu.tus.ac.jp

Abstract. Non-audible HF electrical noise is increasing in recent digital audio equipment. Therefore, in our previous study, we measured results showed that inputting non-audible HF electrical noise which has close two frequency component to the analog input of one analog audio amplifier caused intermodulation distortion (IMD) in the audible band of the output of the amplifier. However, the research was insufficient in consideration of sound deterioration difference among some models of audio amplifier. The consideration of dependency on amplitude and frequency of the two HF noise was also insufficient. In this study, in order to investigate the influence of the plural HF noise on the audible band in detail, we measured spectrum of the output of each six models of audio amplifier with inputting two HF sine wave to analog input. The frequency of the HF noise was varied from 100 kHz to 100 MHz, and the amplitude of the HF noise is also set to small amplitude to consider practical condition. From measured results, it was confirmed that immunity against non-audible HF noise is different in each equipment. These results show the importance of consideration of HF characteristic and countermeasure to the HF noise in circuit design of audio equipment.

1. Introduction
In recent years, high resolution digital audio equipment with personal computer/network connect ability is increasing. Non-audible high frequency (HF) electrical noise which has various frequency components is increasing more and more due to high performance processor and some radio frequency circuit for wireless connection in these digital audio equipment. There are concerns that these non-audible HF noise may cause bad influence to sound playback. The research on the influence of non-audible HF noise is shortage although development on audio equipment for high-fidelity sound playback is progressing.

Therefore, in our previous study, we investigated the influence of non-audible HF electrical noise on the audio signal of one audio amplifier. The measured results showed that inputting plural non-audible HF electrical noise which has close two frequency component to the analog input of one analog audio amplifier caused intermodulation distortion (IMD) in the audible band of the loudspeaker output of the amplifier [1]. However, in the previous study, we have confirmed this sound degradation phenomenon only by one model of analog audio amplifier. In addition, the amplitude of the HF noise is measured with large amplitude (1 Vrms) in order to clearly measure the phenomenon.
Therefore, in this study, in order to investigate the influence of the plural HF noise on the audible band in detail, we researched the occurrence and the difference of tendency / characteristics of this sound deterioration phenomenon among audio amplifier models.

In the measurement, non-audible HF sine wave that has two frequency components was generated by mixing the two output signals from the function generator by a high frequency mixer. This HF noise was input to each of three models of audio amplifiers and three models of digital audio amplifiers, and the IMD in the audible band of each loudspeaker output was measured. The frequency of the plural HF noise was varied from 100 kHz to 100 MHz, and the two frequency difference of plural HF noise was varied from 20 Hz to 20 kHz. In addition, we also investigated the amplitude of the plural HF noise set to smaller amplitude \((17.78 \text{ mV}_{\text{rms}})\) to consider practical condition.

2. Measurement method of IMD in audible band caused by non-audible plural HF noise

Figure 1 shows the setup for measuring IMD in audible band caused by non-audible plural HF noise. We measure the spectrum of the loudspeaker output of the audio amplifier by the audio analyzer (Audio Precision, APx525) when non-audible HF noise that have two frequency components (plural HF noise) is input to the analog audio input (RCA unbalanced line input).

The plural HF noise is generated by mixing the two output sine waves from the function generator (Tektronix, AFG3252) by the high frequency mixer (R&K, PD010). The frequency of the plural HF noise was selected that the frequency difference between the two sine waves was prime number 2017 Hz, e.g. 100 MHz and 100.002017 MHz, in order to distinguish the frequency component caused by the IMD from buzz noise components. In the experiments shown in section 2.1, 2.2, and 2.3, the amplitude of each HF noise is set to 1 V_{\text{rms}} in order to observe the influence remarkably, and that amplitude is set to the range from 0 dBV (1 V_{\text{rms}}) to -35 dBV (17.78 mV_{\text{rms}}) to consider practical condition. The gain of the audio amplifier is set to 0 dB at 2017 Hz sine wave.

Actually the function generator outputs somewhat noise also in audible band besides the HF noise. Therefore, in order to observe the targeted noise component caused in the audible band by the plural HF noise, we also measure the noise floor of the measurement apparatus and the targeted audio amplifier when the function generator outputs a DC 0 volt arbitrary waveform signal, i.e. no signal.

2.1. Audio amplifier' model dependency of the IMD in the audible band

We measure and compare the frequency spectrum in audible band of the loudspeaker output of 3 models of analog audio amplifiers (Model A, B, and C) and 3 models of digital audio amplifiers (Model D, E, and F) in order to consider the audio amplifier’ model dependency of the IMD characteristics in audible band caused by non-audible plural HF electrical noise.

2.2. Plural HF noise frequency dependency of the IMD in the audible band

In order to investigate the frequency dependency of the IMD in audible band caused by the plural HF noise which inputs to the audio equipment, we measure spectrum of a loudspeaker output by the audio analyser when the plural HF noise is inputted. In this experiment, frequency of the plural HF noise is
varied from 100 kHz + 2017 Hz to 100 MHz + 2017 Hz with 28 logarithmically equal frequency intervals.

2.3. Plural HF noise frequency difference dependency of the IMD in the audible band
To investigate the influence of the difference between the frequency of two HF noise component which is inputted to the audio equipment on the IMD, we measure spectrum of a loudspeaker output of the three models of audio amplifiers (Model A, C, F) by the audio analyzer. The frequency difference of the plural HF noise component is varied from 20 Hz to 20 kHz with 200 Hz frequency interval. The base frequency of the plural HF noise is 40 MHz for model A, 600 kHz for model C, and 2 MHz for model F respectively. These frequency was the frequency that the largest IMD are caused in the measurement shown in section 2.2.

2.4. Plural HF noise amplitude dependency of the IMD in the audible band
In the measurements in the section 2.1, 2.2 and 2.3, the amplitude of the HF noise was measured with a 0 dBV (1 Vrms) large amplitude in order to measure the IMD caused by the HF noise clearly. However, since the noise level in the practical condition seems to be considerably low, we measure the IMD caused by the plural HF noise with smaller amplitude. The amplitude of the plural HF noise is varied from 0 dBV (1 Vrms) to -35 dBV (17.78 mVrms) with 5 dBV amplitude intervals.

Measurement below -30 dBV is performed by inserting 10 dB attenuator (BNC coaxial type, Yuetsu Seiki, band 3 GHz) after the high frequency mixer as shown in fig. 2, since the function generator used in this experiment can output above -25 dBV.

Figure 2. Apparatus setup for measuring the IMD caused by plural HF noise these amplitude is below -30dB.

3. Experimental Results

3.1. Audio amplifier’ model dependency of the IMD in the audible band
Figure 3 shows frequency spectrums in audible band of the loudspeaker output of each audio amplifier when the plural HF noise of 100 MHz and 100.002017 MHz was inputted and frequency spectrums of their noise floor. Figure 4 shows the difference spectrum between the spectrum of each audio amplifier when the plural HF noise was inputted and the spectrum of their noise floor.

From figure 3 and 4, it is confirmed that audible band noise (2017 Hz) component is observed in all models of the amplifiers. It is also confirmed that this audible noise (2017 Hz) component is the IMD caused by the inputted plural HF noise, since this frequency 2017Hz is just the difference frequency between 100 MHz and 100.002017 MHz. The magnitude and characteristic of this IMD varies and depends on the model of amplifier greatly. The spectrum from model A has integral order harmonics (2017 Hz, 4034 Hz, 6051 Hz, etc.) of the IMD. In contrast, only fundamental component (2017 Hz) of the IMD was observed from other models.
Figure 3. Frequency spectrums in audible band of the loudspeaker output of each audio amplifier when the plural HF noise of 100 MHz and 100.002017 MHz was inputted and frequency spectrums of their noise floor.

Figure 4. Difference spectrum between the spectrum of each audio amplifier when the plural HF noise was inputted and the spectrum of their noise floor.
3.2. Plural HF noise frequency dependency of the IMD in the audible band
Figure 5 shows the amplitude of the 2017 Hz component of the IMD at the loudspeaker output of each audio amplifier when the frequency of the plural HF noise is varied from 0.1 MHz to 100 MHz. This amplitude of the IMD is absolute increase of the IMD that is calculated by subtracting amplitude of the noise floor from the IMD caused by the plural HF noise.

From Fig.5, it is found that the amplitude of the IMD depends on the frequency of the plural HF noise and model of the audio amplifier. The IMD maximum amplitude appeared at 40 MHz for model A, 0.1 MHz for model B, 0.3 MHz for model C, 0.1 MHz for model D, and 1 MHz for model E - F, respectively. It is also confirmed that the amplitude of the IMD and their frequency characteristics greatly depend on model of the audio amplifier.

Although in our previous study [1] using only model A amplifier, the IMD in the audible band was getting larger as the frequency of the non-audible HF noise became higher. However, in this experiment, many models (e.g. Model C, E, and F) tended to decrease IMD after their peaks in the range from 1 MHz to 10 MHz. It seems that these differences of characteristics and dependency for each model of the audio amplifier come from design of electrical circuit and structure which affect to characteristics in non-audible HF band.

3.3. Plural HF noise frequency dependency of the IMD in the audible band
Figure 6 shows the amplitude of the IMD at the frequency difference (f2 - f1) of the two sine waves (frequencies f1, f2) of the HF noise which is varied from 20 Hz to 20 kHz. The base frequency of the plural HF noise was 40 MHz for model A, 0.6 MHz for model C, and 2 MHz for model F.

From figure 6, the amplitude of the IMD in the model A and C was almost equal whenever the frequency difference of the plural HF noise was in audible band. In contrast, the amplitude tended to increase slightly as the frequency difference increased in the model F.

3.4. Plural HF noise amplitude dependency of the IMD in the audible band
Figure 7 shows the amplitude of the 2017 Hz component of the IMD when the amplitude of the plural HF noise is varied from 0 dBV (1 V rms) to -35 dBV (17.78 mV rms). Figure 8 shows the frequency spectrum of the loudspeaker output of the audio amplifier when the -30dBV plural HF noise was inputted to the model A of the audio amplifier.

From figure 7, it is found that there is a direct relationship between the amplitude of the plural HF noise and the amplitude of the IMD in all three models. The -85 dBV IMD which seems to have some auditory influence is caused in the model A, even if the amplitude of the plural HF noise is small like -30 dBV.
4. Conclusions

In this study, in order to investigate the influence of the non-audible plural HF noise on the audible band in detail, we investigated from the viewpoint of audio amplifier model dependency of the IMD in the audible band, plural HF noise frequency dependency and frequency difference dependency of the IMD, and plural HF noise amplitude dependency of the IMD.

As a result, we found the followings:

- The amplitude of the IMD caused by the plural HF noise varied depending on the model of the audio amplifier. Their susceptibility is also different in each model.
- The susceptibility to the plural HF noise varied depending on the frequency of the plural HF noise. The frequency characteristics greatly depended on the models.
- The IMD did not almost depend on frequency difference of the plural HF noise.
- Audible levels IMD was caused in some audio amplifiers, even if the amplitude of the plural HF noise was small.

From these results, it was found that non-audible high frequency electrical noise affected the audible band and caused sound quality degradation. These results show the importance of consideration of high frequency characteristic and countermeasure to the high frequency noise in circuit design of audio equipment.

5. References

[1] Kobayashi D, Kuwabara T and Yoshida T 2017 The influence of non-audible high frequency noise on the playback sound of audio equipment Proc. of 2017 IEEE 6th Global Conference on Consumer Electronics (GCCE 2017) pp 642-644