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Hi-pass Pink Noise: Its Acoustic Features and Standard Volume

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Abstract

This paper reviews the irregular acoustic properties of pink noise and its improper use as a common reference sound source, and proposes hi-pass pink noise as a new reference sound source. Hi-pass pink noise can be identified as a sound source created by eliminating unnecessary energy below the audible pitch range in pink noise. Compared to regular pink noise, hi-pass pink noise of 20 Hz had a minimum of 20% reduction in energy and a marginal increase of 0.7dBFS amplitude, while hi-pass pink noise of 40 Hz had 30% reduction in energy and 1.6dBFS marginal increase in amplitude. In spite of such changes in physical features, hi-pass pink noise does not produce any audible difference. The paper also suggests that Comfortable Maximum Level (CML) can be utilized as a standard volume when comparing multiple sound sources.

Keywords: *Pink noise, Hi-pass Pink Noise, MCL, CML, A7B*

1. Introduction

Measuring and analyzing sound sources have always required a standardized system. Currently, white noise and pink noise are used as sound sources in many occasions. White noise sound source is usually used to obtain impulse response of frequency energy and to test the performances of machines. On the other hand, pink noise produces equal energy over the whole frequency range in logarithmic scale, and thus shows similar characteristics to noises from the nature. Since pink noise has constant energy irrespective of time, we can exclude time factor from pink noise and use pink noise in audio systems or as a reference sound source for analytical purposes. Furthermore, pink noise is widely used for research purposes such as for accumulating various noises [1, 2].

2. Acoustic Features of Pink Noise

Spectral density for amplitude of pink noise is inversely proportional to that of frequency and thus is called flicker noise or 1/f noise. The characteristic feature of its frequency shows that for every increase of an octave in white noise, there is a decrease of 3dB in pink noise. Pink noise is used for replacing ambient noise in sound-related experiments. It is also used in theaters and studios where the human ears must evaluate the quality of sound.

S(f) in Eq. (1) refers to the energy spectral density. The value of α in pink noise is close to 1. Types of ambient noise and change of energy spectral density are represented in Eq. (2) where α becomes 0 in direct currents and has the largest energy spectral density.

$$S(f) \propto 1/f^2 \quad (1)$$

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$$\text{White Noise}: \alpha = 0, S(f) = \frac{1}{f^0} = \frac{1}{1} = 1$$
$$\text{Pink Noise}: \alpha = 1, S(f) = \frac{1}{f^1} = \frac{1}{f} \quad (2)$$
$$\text{Brown Noise}: \alpha = 2, S(f) = \frac{1}{f^2}$$

Frequency spectrum of pink noise naturally spreads over wide ranges and is used for input/output data in various fields. There is a notable difference between α being close to 1 and α being in an approximately wide range of $0<\alpha<2$.

Human auditory range is commonly known to be between 20 to 20000Hz, but every sound source contains inaudible pitch with some energy. This is a natural phenomenon and does not cause any significant issues. However, when sound source is digitalized, it has a limited domain of 9dBFS and is projected within the regenerative frequency range of a speaker in use. Depending on the capacity of a speaker unit, a specific signal can be played within the limited frequency domain. When the input energy exceeds this limit, various problems may arise [3, 4].

First of all, as unnecessary calculations are implemented by the speaker's software, unnecessary inputs are to be created in the amplifier. This causes a waste of energy and further requires additional filters. Receiving the sound in unplayable scales, the output terminal of a speaker may produce unnecessary movements of the entire system. This is the same reason why some high quality audio systems provide various frequency inputs for each speaker unit. When the system receives energy beyond its capacity without passing through a band pass filter and any change in the frequency range is detected, it should be interpreted as a distortion, not a regular input [5].

In particular, since excessive energy below the range of infra-sound includes large irregular waves, it produces sporadic wave peak distributions and results in some waste in the range of dBFS. Sound sources produced using common methods as well as sounds of nature do not have these problems stated previously because they do not produce large amount of energy in the inaudible range. However, pink noise and brown noise [6] are the cases of extraordinary exceptions. In pink noise, energy doubles for every octave decrease, while it quadruples for brown noise.

Theoretically, pink noise does not exist around 0Hz since energy becomes infinite. Therefore, in order to produce a feasible pink noise, increase of energy should be blocked below a certain limit of frequency. However, there is no standardized system determining when to restrict the increase of energy in a certain frequency range, and thus causing different acoustic properties of various pink noises in use produced by different programs.

3. Acoustic Features of Hi-pass Pink Noise

Hi-pass pink noise can be identified as a sound source created by eliminating unnecessary energy below the audible pitch range in pink noise. A common "Hi-Pass Pink Noise" is simply a pink noise that has passed the 20Hz limit of frequency range. For this research, the frequency ranges applied for hi-passing are classified into 6 ranges and volume for each range was analyzed.

Figure 1 shows an enlarged hi-pass pink noise spectrum below 100Hz. The window function applied is Blackmann and the size of FFT is 16384. While regular pink noise shows rapid increase in energy along with frequency decrease, hi-pass pink noise does not contain any energy below certain frequency.

Figure 2 shows wave changes for hi-pass pink noise in intervals of 0.5 seconds. Waves of 40Hz and 60Hz hi-pass pink noise have been omitted because they cannot be seen through the naked eye.

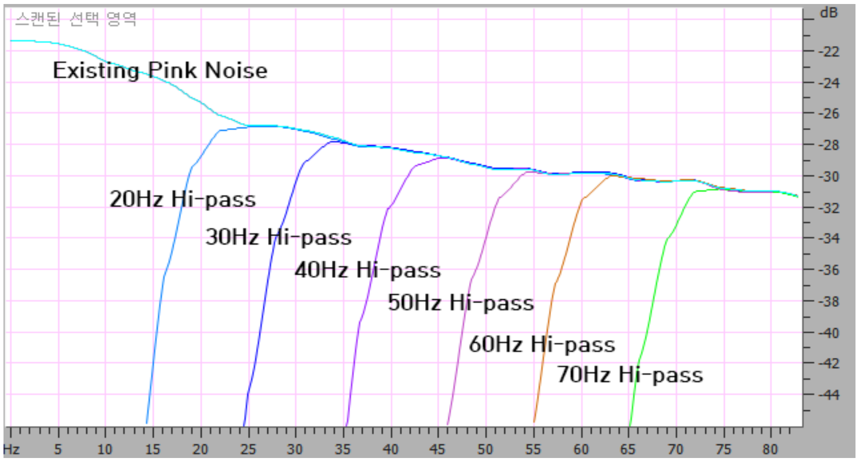
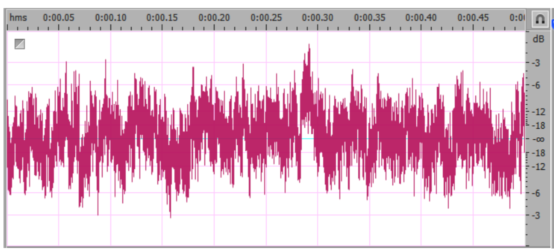
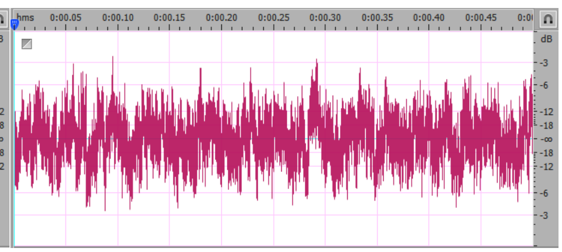


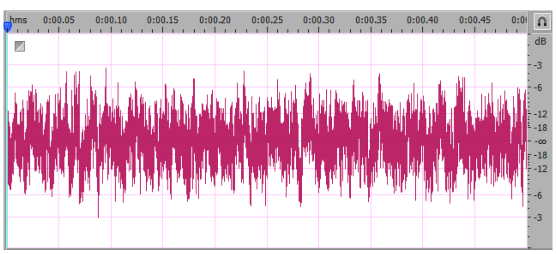
Figure 1. Spectrum of regular pink noise and hi-pass pink noise



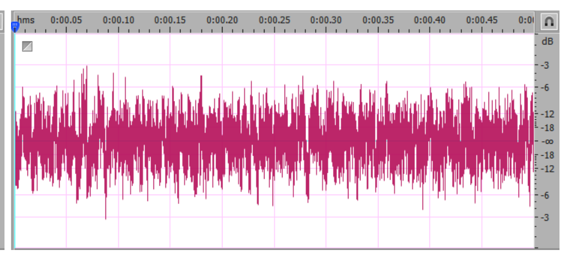
(a) Regular pink noise



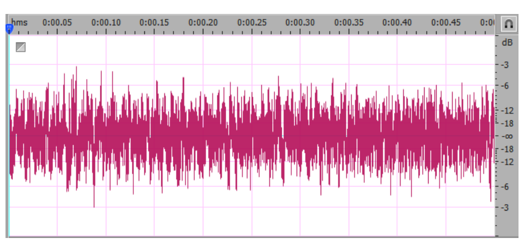
(b) 20Hz Hi-pass pink noise



(c) 30Hz Hi-pass pink noise



(d) 50Hz Hi-pass pink noise



(e) 70Hz Hi-pass pink noise

Figure 2. Pink noise wave forms at 0.5 seconds section

Regular pink noise (Figure 2(a)) clearly shows low frequency in the middle of the wave forms with high pitch randomly formed over low frequency. These random frequencies sporadically create unwanted peaks. Pink noise of 20Hz shows a decrease in the central part of a random low frequency as well as a decrease in maximum amplitude. This tendency continues as hi-pass frequency increases until reaching 70Hz where the curve of a random low frequency cannot be seen by the naked eye and sporadic peaks also disappeared.

Table 1 shows statistical analysis of amplitude for one minute in all the types of pink noise. The results may differ depending on the type of filter. Hi-pass pink noise of 20Hz has amplitude of 0.7dBFS with 23% of reduced energy ratio. Hi-pass pink noise of 60Hz has amplitude of 2dBFS with 33% of reduced energy ratio. The increase of dBFS margin is significant, especially to sound source producers who need to secure as many dynamic ranges as possible. Furthermore, for experimental or sound effect purposes, the dB margin difference plays an important role for preventing unwanted peaks when adding pink noise from existing sound sources. Moreover, there is a 20% energy reduction with the lowest hi-pass pink noise minimizing unnecessary loads for amplifiers and woofers.

Table 1. Amplitude statistics and energy comparison of hi-pass pink noise

Hi-pass Frequency [Hz]	0	20	30	40	50	60	70
Maximum Amplitude [dBFS]	0.0	-0.7	-1.2	-1.6	-1.8	-2.0	-2.1
Maximum RMS Amplitude [dBFS]	-10.61	-12.06	-12.08	-13.03	-13.25	-13.30	-13.35
Minimum RMS Amplitude [dBFS]	-15.03	-15.33	-15.40	-15.60	-15.74	-15.79	-15.95
Average RMS Amplitude [dBFS]	-13.12	-14.08	-14.30	-14.50	-14.66	-14.78	-14.90
Eliminated Energy Ratio [%]	0	23	27	30	32	33	34

Music uses the largest frequency range among all digitalized sound sources. Figure 3 shows a magnified spectrum of the frequency range below 1000Hz for regular pink noise, hi-pass pink noise, and 4 music sound sources produced after 2005. In order to analyze infra-sound range, extremely large FFT size (66536) was applied here. Although the sound sources shown in Figure 3 differ in genre, production companies, and engineers, they all have no energy below certain frequency. Other sound sources would show similar characteristics as well. The 4 short vertical lines represent points of lowest frequency where a rapid decrease (hi-passed in other words) was observed for each sound source. When applying hi-pass filters, there is generally more than 6dB/oct gradient decrease below certain frequency, and the point of showing 3dB decrease is known as a shut-off range. The lowest frequency point was determined by a minimum of 24dB/oct gradient energy decrease for all sound sources.

Out of additional 50 sound sources collected and analyzed for this research, the lowest band was 35Hz, but most of sound sources are in between 40 and 60Hz, a proper frequency range that can be hi-passed. There is no significance for the human auditory sense if a sound source is under the range of corresponding frequency in a broadband sound source.

The reason for eliminating energy under certain frequency in all sound sources is not only because the sound itself is not recorded, but also because the source producers want to secure as many dynamic ranges as possible through eliminating unnecessary energy [7]. Consequently, hi-passing will bring high quality sound as well as expanded ranges for sound.

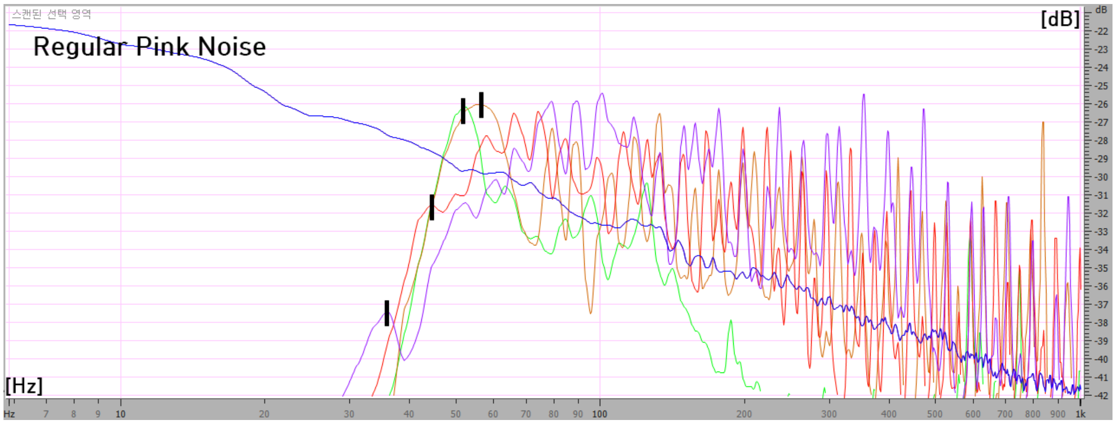


Figure 3. Portion of 4 different sound sources and regular pink noise (0～1000Hz, FFTsize: 65536)

Figure 4 shows an overall spectrum graph of regular pink noise and 6 recently produced sound sources. To compare their general spectrum forms, the FFT size was 4096, 1/16 of the one used in Figure 3 and the frequency was marked with an extended range from 0 to 22050Hz. The 6 corresponding sound sources were randomly chosen, but any other sound sources would show similar spectrum to the one shown above.

The range above 50Hz in pink noise has similar frequency characteristics to that of actual sound sources being produced at the market. However, below certain frequency, its acoustic characteristics are completely opposite to what we hear. These results prove that using pink noise as a reference sound source is implausible due to its irregular acoustic properties, and regular pink noise should be replaced by hi-pass pink noise.

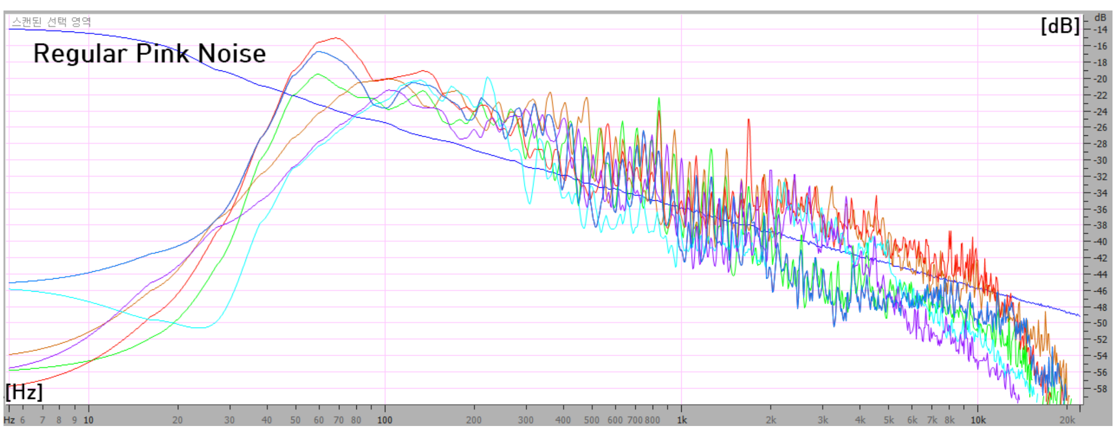


Figure 4. Overall spectrum of 6 different sound sources and regular pink noise (0～22050Hz, FFTsize: 4096)

4. Auditory Features of Hi-pass Pink Noise

Table 2 shows the results of the different auditory judgments on pink noise with a 60dB(A) standard volume compared to that of hi-pass pink noise. The test was proceeded by 10 studio sound engineers and 20 ordinary people wearing experimental headphone "Sennheiser HD650." Pink noise and hi-pass pink noise were played consecutively to test whether or not participants could detect the difference.

The difference between 20Hz hi-pass pink noise and regular pink noise was not noted by any one among the participants. From 30Hz hi-pass pink noise on, a few number of participants started to recognize the difference, and as the frequency was increased, more participants were able to recognize the difference. These recognitions became clearer through repeated listening and finally participants recognized the difference right on the spot.

In conclusion, 20Hz hi-pass pink noise can be used widely as a reference sound source for auditory tests, and 40Hz hi-pass pink noise can be used for general purposes other than for experimental purposes.

Table 2. Ratio recognizing the difference between regular pink noise and high-pass pink noise

Hi-Pass frequency [Hz]	20	30	40	50	60	70
Studio Engineer [%]	0	10	20	50	80	100
Ordinary people [%]	0	0	5	15	40	60

According to the acoustic properties of hi-pass pink noise as we have analyzed in the previous section, there is a significant difference between the two frequencies and wave forms of regular pink noise and hi-pass pink noise. However, when listening to both noises, the sound volume was recognized exactly the same. This is due to the fact that the validity of the equal-loudness contours, applied to all sound sources, remains intact in the broad bandwidth.

5. The Experiment for Setting up a Standard Volume of Pink Noise

Three conditions must be satisfied for any reference sound source in order to be used to effectively measure sound volume that we hear. Firstly, its acoustic properties should be similar to those of human frequency properties. Since the relationship between human frequency and energy is a kind of logarithmic scale, using a sound source with equivalent energy per octave is important. It stimulates the human auditory sense. Secondly, we should not have any change in energy with respect to time. The human auditory sense detects any energy change even if the sound source produces the average energy identical over a certain period. Thus, unnecessary variables should be removed in advance. Lastly, in order to apply the reference sound source consistently to any case, its acoustic characteristics must be simple and thus anyone should be able to produce and apply the sound source with the same quality.

In conclusion, pink noise satisfies all the conditions stated above. It is the most suitable sound source for measuring sound volume recognized by hearers. Regular pink noise is used as a reference sound source in various cases, but a standard volume has not been suggested.

To select an appropriate standard volume, 10 sound engineers and 20 ordinary people in the ages between 20 and 30 with no hearing problems were chosen for identifying sound volume. This experiment was conducted to obtain a general standard volume for generic use only, not to postulate an exact value. The standard volume utilized in this experiment has been marked down by decrease of 10dB(A) as in 90db(A), 80, 70 60, 50, and so on, for the purpose of securing safety and applicability with preference in a relatively low volume for generic use.

There are several criterions to evaluating loudness [8]. However, measuring volume accurately only based on the human auditory sense is a very difficult procedure and inevitably produces different results depending on the individual capacity of each hearer [9]. Nevertheless, MCL (Most Comfortable Level) and UCL (Uncomfortable Level) [10] can be clearly classified relatively and is in a popular use with high reliability.

In this research, the most suitable volume for pink noise has been identified as the one with CML (Comfortable Maximum Level). This is the maximum volume within the domain of comfort from the perspective of the hearer who is actively listening to a sound source (music in a typical case). CML can be interpreted as the advised and optimal standard volume, and be utilized to set up sound volume compatible for each case based on any relative difference between sound sources. To calculate the CML value, the mean of MCL and UCL, relatively accurate standards, is applied. The equation of CML is as follows:

$$\text{Comfortable Maximum Level: CML} = \frac{\text{MCL+UCL}}{2} \quad (3)$$

The experiment was conducted in an ascending fashion. Before the experiment, MCL was identified to participants as the point a hearer stops feeling that certain sound, which the hearer needs to hear, is quiet. On the other hand, UCL was identified as the point a hearer feels unpleasant because certain sound is too loud.

30 participants reported that the mean of CML was 62.8dB(A) and CML was observed between 59.7dB(A) and 66.4dB(A). Based on this result as well as the overall conditions to set up the standardized volume system as mentioned before, the standard volume for pink noise was determined as 60dB(A), a down-marked value from the mean value.

6. Conclusion

Although pink noise is being widely used as a reference sound source for acoustic measurements and research purposes, detailed researches concerning acoustic properties of pink noise have not been realized. This study analyzed the irregular acoustic properties of regular pink noise and suggested hi-pass pink noise as a better replacement.

Even though hi-pass pink noise differs from regular pink noise with respect to frequencies, wave forms, and energy distributions, it was recognized exactly the same as regular pink noise in terms of volume and sense in the auditory experiment. Hi-pass pink noise has several benefits in eliminating unnecessary frequency ranges which do not affect the auditory recognition, reducing the unnecessary energy load on amplifiers and speakers, and increasing the amplitude margin of dBFS in digitalized sound sources.

Moreover, 60dB(A), as suggested in this paper, which utilizes the concept of CML, can be effectively used as a standard volume for reference sound sources including pink noise. By applying the system, we can produce a proper sound source without having any technical difficulty directly at the site.

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