PERMISSIBLE VALUE OF GROUP DELAY DISTORTION ON TONE QUALITY DUE TO LOW-PASS FILTERS

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Abstract

Generally, in low-pass filters with very steep attenuation characteristics, group delay distortion occurs near the cut-off frequency. As a result, it is seen that the group delay distortion has a distinct influence on tone quality.

Consequently, we have examined degradation of tone quality due to group delay distortion from low-pass filters, and from the results of our experiments, it has been verified that the permissible value of group delay distortion on tone quality due to low-pass filters is about 2 ms, in the high frequency range.

In digital audio systems, low-pass filters with very steep attenuation characteristics (for example, Chebyshev-type filters) have been usually used to minimize aliasing noise and eliminate higher harmonic components.

Then, we have verified the permissible value of the attenuation characteristics of low-pass filters in digital audio systems, from the results of the permissible value of group delay distortion on tone quality due to low-pass filters.

1. Foreword

During the last several years, an increasing amount of work in recording studios and broadcasting stations has come to be done using PCM multitrack tape recorders. In such work, mixdown and overdubbing are normally done several times, but, at the present stage where the audio mixing console has not been completely digitized, the analogue-to-digital and digital-to-analogue conversions need to be conducted repeatedly.

But, in digital audio systems, low-pass filters with very steep attenuation characteristics (for example, Chebyshev-type filters) have been widely used to minimize aliasing noise and eliminate higher harmonic components.

As previously described, in low-pass filters with very steep attenuation characteristics, group delay distortion occurs near the cut-off frequency. Consequently, it is seen that the distortion has a distinct influence on tone quality.

However, such a degradation of tone quality caused by the influence of group delay distortion has not yet been discussed in detail.

Therefore, we conducted a listening test and studied the effect of group delay distortion on tone quality and in this way verified the permissible value of group delay distortion on tone quality due to low-pass filters and, as an applied case of using the value, we have verified the permissible value of the attenuation characteristics of the low-pass filters in digital audio systems.

2. Method of Experiment

We adopted a method of producing sound with the group delay distortion corrected and the same sound without correction, both using FFT(Fast Fourier Transform), and of judging the difference in tone quality between the two (alternative judgment). The low-pass filter used was the 11th order Chebyshev-type (Attenuation characteristic : 280 dB/oct) and four different cut-off frequencies were used, viz., 10, 12, 15 and 20 kHz. And by cascade connection, the attenuation characteristics were set at 280, 560, 840 and 1120 dB/oct (See Fig. 1).

(1) Production of Test Signals

We used the pulse train of square wave, with input signal Si, pulse width 25 μs and pulse interval 5 ms.

As shown in Fig. 2, we put this input signal through to the LPF, which is the transfer function $F(\omega)$, then FFTed it, and did the following calculations.

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$$S_1(\omega) = [Si(\omega) \cdot A(\omega) \cdot e^{j\phi(\omega)}] \times 1$$
$$= Si(\omega) \cdot A(\omega) \cdot e^{j\phi(\omega)} \quad \text{【 uncorrected sound 】}$$
$$S_2(\omega) = [Si(\omega) \cdot A(\omega) \cdot e^{j\phi(\omega)}] \,/\, e^{j\phi(\omega)}$$
$$= Si(\omega) \cdot A(\omega) \quad \text{【 corrected sound 】}$$
$$\text{However, } F(\omega) = A(\omega) \cdot e^{j\phi(\omega)}$$

After these calculations are done, they are IFFTed, converted from digital to analogue, and recorded as test signals (S1,S2), on a PCM tape recorder.

(2) Presentation of Test Signals

In order to obtain fair judgment results, we combined A (S1) and B (S2) in various sequences as shown in Fig. 3 and arranged a total of 20 pairs at random; five pairs each of (A,B) and (B,A) and ten pairs of (A,A). The duration of the signal presented was, as shown in the same Fig. 3, a pair of 6 seconds each and the rise-up time and breaking time were both set at 50 ms. The evaluation was done by ten audio engineers using headphones, with the listening level set at the equivalent of 80 dBspl.

Using the experimental method described above, we conducted a series of audibility tests to judge whether there is any difference in tone quality when using each of the above-mentioned 16 different filters. And, from the results of the tests, the correct-answer ratio was obtained for each of the ten evaluators.

3. Results of the Experiment

The correct-answer ratios of all ten evaluators are shown in Fig. 4. As can be seen from the example shown in Fig. 1, with regard to the influence on tone quality from group delay distortion of low-pass filters, a noticeable delay occurs only in the signal components near the cut-off frequency, with the result that, in terms of audibility, one gets the feeling that this particular frequency component is emphasized (See Table 1).

Therefore, as can be noted from Fig. 4, the steeper the attenuation characteristics and the lower the cut-off frequencies, the higher the detection ratio of group delay distortion.

This degradation of tone quality caused by group delay distortion can be detected from an attenuation characteristic of 560 dB/oct or higher when the cut-off frequency is 10 or 12 kHz, and can be detected from an attenuation characteristic of 1,120 dB/oct when the cut-off frequency is 15 or 20 kHz.

In either case, it can be seen that degradation is detected when the maximum delay time of the signal components near the cut-off frequency becomes about 2 ms.

4. Conclusion

From the experiments described above, it has been clarified that the permissible value of group delay distortion on tone quality due to low-pass filters is about 2 ms, in high frequency ranges of 10 kHz to 20 kHz.

And as an applied case of using the permissible value of group delay distortion on tone quality due to low-pass filters, the value sets limits to the attenuation characteristics of low-pass filters in digital audio systems. From the results of the experiment, it has been clarified that in the case of work where analogue-to-digital and digital-to-analogue conversions are done repeatedly the attenuation characteristics of low-pass filters that are permissible as a system will be about 1000 dB/oct when the required bandwidth is set at less than 20 kHz.

Also, in PCM sounds, viz., Mode A of satellite broadcasting in Japan, audio transmission circuits, etc., when the required bandwidth is set at 15 kHz or less, the permissible attenuation characteristics will be about 840 dB/oct, which corresponds to the attenuation characteristic value in the case where the 11th order Chebyshev type (280 dB/oct) is connected in a three-stage cascade.

Therefore, in cases where the attenuation characteristics of low-pass filters exceed the above-mentioned values and, moreover, the program sound in question contains high frequency components near the cut-off frequency, sufficient care needs to be taken because of the possibility of the group delay distortion affecting tone quality.

In this experiment, we have verified the permissible value of group delay distortion in the high frequency range of more than 10 kHz and that the degradation of tone quality can be detected when the maximum group delay time becomes about 2 ms.

Therefore, we intend to verify the permissible value of group delay distortion in the low or middle frequency range, and to study the cause of the detection.

5. Reference

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: Influence of Group Delay Distortion of Low-Pass Filter on Tone Quality
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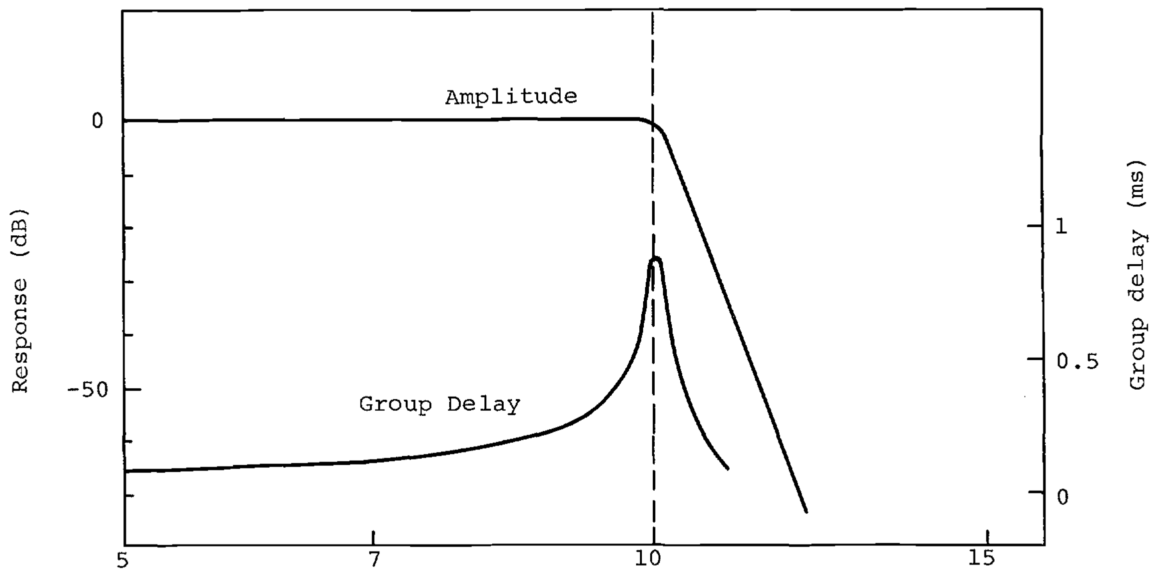

Fig. 1 Amplitude response and group delay of a low-pass filter (Attenuation characteristic: 280 dB/oct)

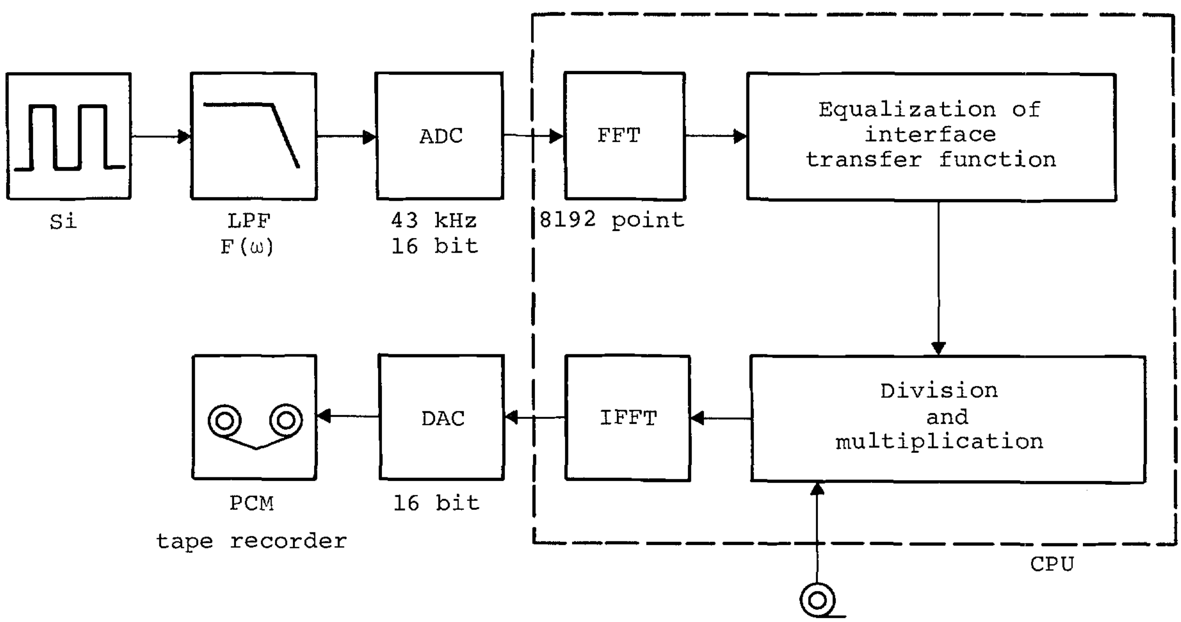

Fig. 2 Method of producing test signals.

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Table 1. Maximum delay time of low-pass filters

Cut-off frequency	Attenuation characteristic (dB/oct)			
	280	560	840	1120
10 kHz	0.9 [ms]	1.8 [ms]	2.7 [ms]	3.6 [ms]
12 kHz	0.75	1.5	2.25	3.0
15 kHz	0.58	1.16	1.74	2.32
20 kHz	0.45	0.9	1.35	1.8

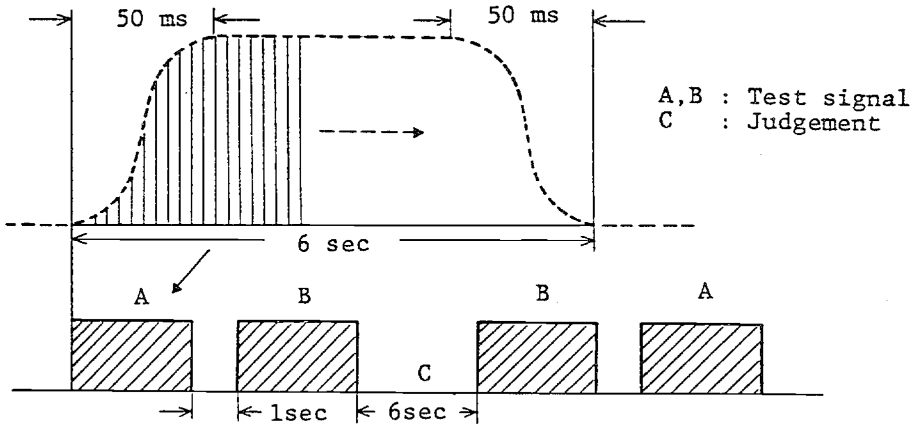

Fig.3 Presentation of test signal

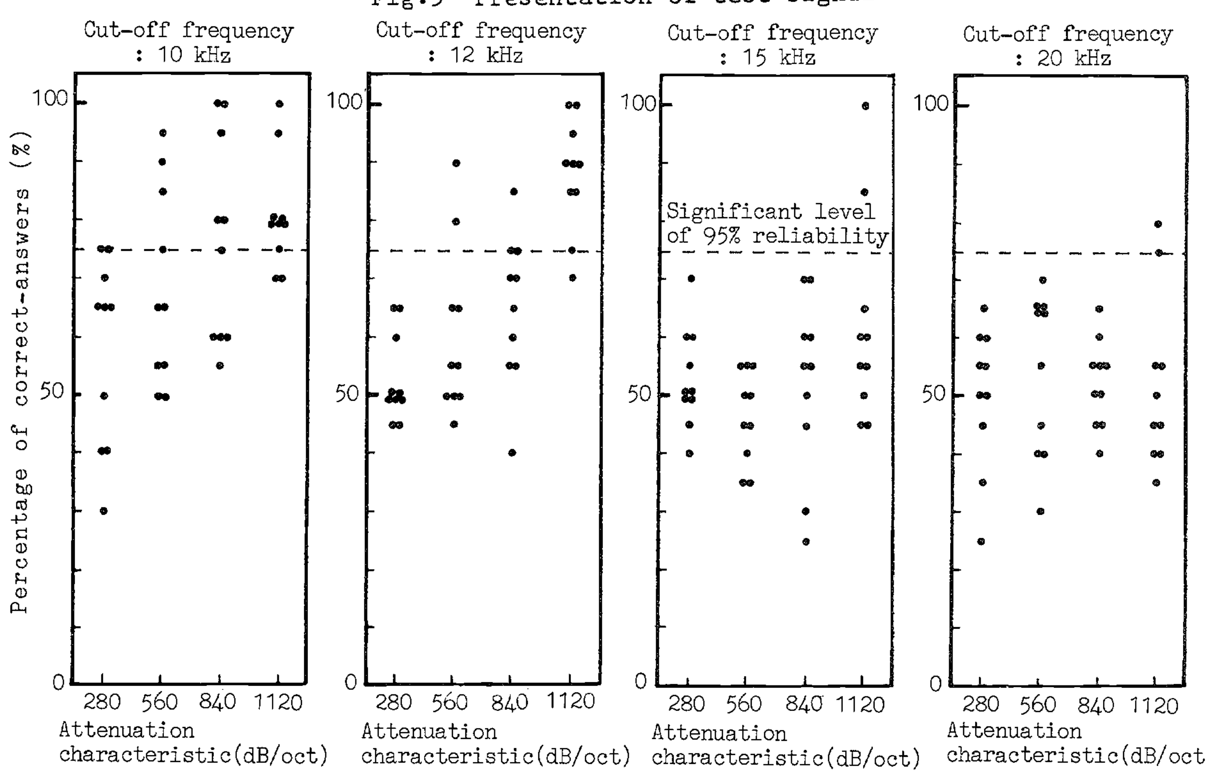

Fig.4 Relation between percentage of correct-answers and attenuation characteristic

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