METHODS TO ELIMINATE THE BASS CANCELLATION BETWEEN LFE AND MAIN CHANNELS

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We have identified the problem of the degradation of bass sound from the main channel, caused by the influence of LFE, and we have proposed a solution. However, it is necessary to consider the encoder and monitor environment. In this paper, the entire process of the recording and reproduction of an LFE is described. We summarize the current state of the adverse effects caused by LFE and introduce a concrete example of the solution and the method of verification. Moreover, the current issue of reproduction in consumer equipment is described.

INTRODUCTION

The low frequency effect (LFE) was originally designed as an actual "effect" to reproduce the different sounds from the main channels. However, LFE has also been widely used for the bass extension of the main channels in surround music. We had raised the issue that LFE degrades the bass sound of the main channels in surround music [1].

On the other hand, the LFE is usually treated as an "option" like as described in [2]; therefore, the confusion regarding the recording, monitoring and reproduction of LFE still persists.

In this paper, we comprehensively summarize the current state of the adverse effects caused by LFE and introduce a concrete example of the solution and the method of verification.

1 CANCELLATION PROBLEM

1.1 Methods of creating an LFE channel

First, we consider the techniques for recording an LFE channel. These can be roughly classified into two methods: 1. LFE is created from a different sound source and 2. LFE is created using the bass frequency of the main channels (Fig. 1). In a movie sound track, both methods are widely used. In surround music recordings, the latter is commonly used.

If an LFE is created from a different sound source, regardless of how the LFE channel is recorded, it does not change the sound of the main channel itself. However, when it is created by using the bass frequency of the mains, the LFE has a high correlation to the main channel; it changes the sound of the main channel. Note that, even when an auxiliary microphone is used for creating an LFE, there is a high correlation between the mains and the LFE; this is due to the low separation of the microphone at low frequencies.

1.2 Cancellation between LFE and the mains

We now consider the influence exerted by the LFE on the mains. We created a simple model that represents the LFE and one of the mains; this is reproduced ideally in a listening room, as shown in Fig. 2.

We evaluate the impulse response of each signal, frequency response and group delay of the summed signal, and the phase difference between two signals. An 8^{th} order Linkwitz-Riley low-pass filter is used, where the cut-off frequency is 100 Hz, and the gain of the LFE is set to –6 dB, 0 dB, and +6 dB. The solid line represents 0 dB; the dashed line, –6 dB; and the chained line, +6 dB.

The results are shown in Fig. 3. The impulse response and the phase difference are displayed only for an LFE gain of 0 dB. This is because the LFE gain changes only the amplitude of the impulse response of the LFE and not the phase difference. The dotted line in the phase difference indicates that the magnitude of the LFE is less than –20 dB, and the phase difference observed in this frequency is not significant. In Fig. 3, heavy cancellation caused by the LFE is observed. The frequency response registers a heavy dip due to the cancellation, and the degree of the dip alters with the gain of the LFE. In the phase difference, it is almost

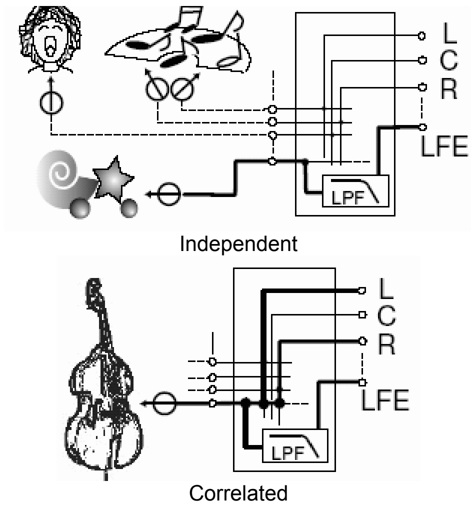

Figure 1: Various methods of creating an LFE channel

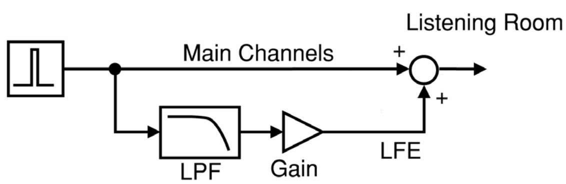

Figure 2: Simplified model of LFE reproduction

"out of phase" around the cut-off frequency. In the group delay, a large peak and a dip are observed. This implies that the timing of the sound is altered by the change in frequency; therefore, the bass sound becomes unstable and dull.

The impulse response shows that the occurrence of this phenomenon can be attributed to the delay in the LFE in the time domain. In this condition, a peak-to-peak delay of approximately 8 ms is observed in the impulse response.

This simple simulation shows that the use of LFE in music to obtain "massive bass," produces a result that spoils the important information in the bass sound. Further, the degree of cancellation is not consistent; it is highly influenced by the gain set-up in the listener's environment. This problem always occurs when an LPF with a correlation to the main channels is used in the LFE channel.

1.3 Current situation of LFE recording

We briefly examined over 50 titles of music recordings in DVD, DVD-Audio, and SACD formats in terms of the matching of the LFE and the mains.

We compared the waveforms of the mains and the LFE in the solo part and measured the phase difference

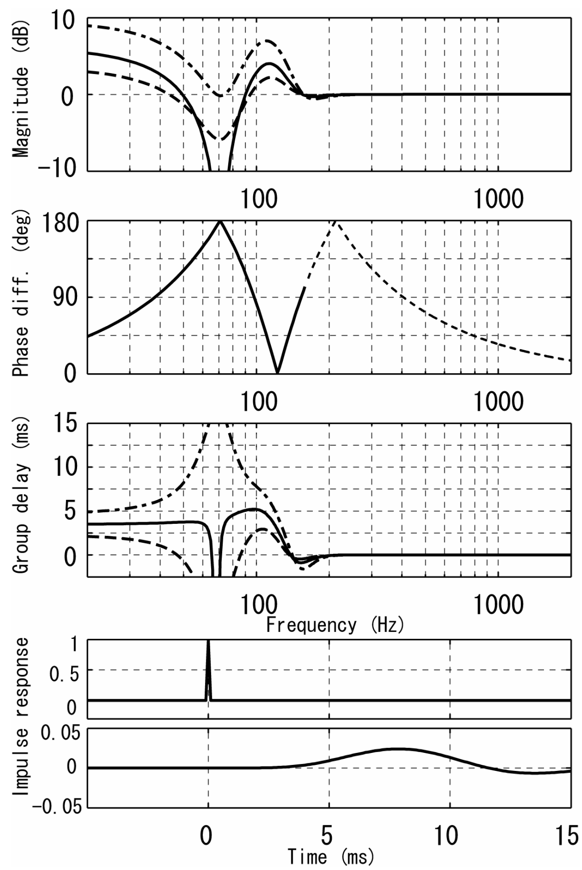

Figure 3: Influence of a low-pass filter of LFE

between the LFE and the mains using SmaartLive [3]. This measurement method is described in the subsequent sections.

This examination indicated that almost all recordings exhibit the cancellation problem with varying degrees. Fig. 4 shows an example imported from a DVD. A part of the kick drum solo is recorded in the center channel (top), and an LFE (bottom) is created from the center channel. In this example, in the time domain, a delay of about 7 ms is observed in the LFE when compared to the center channel. Phase wise, the center channel and the LFE is almost "out-of-phase". This problem requires an immediate solution.

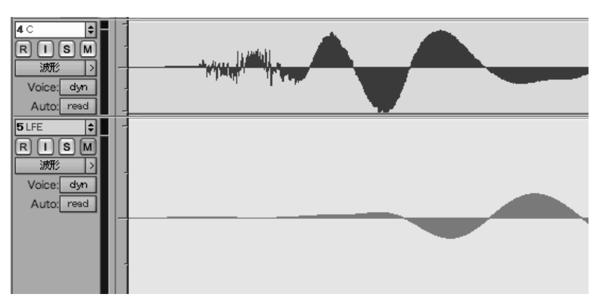

Figure 4: Example of a phase mismatch in a DVD

2 SOLUTION TO THE CANCELLATION PROBLEM

Solving the cancellation problem involves matching the LFE and the mains in terms of phase and time. We compare the following practical method for matching the LFE and the mains:

- Inverting the phase of the LFE (INV)
- Inserting an all-pass filter in the main channels (APF)
- Incorporating a proper delay in the main channels (DLY)

We evaluate these three methods by comparing the impulse response, frequency response of summed signal, group delay of summed signal, and phase difference between the main channels and the LFE. Fig. 5 shows the block diagram for each method.

The gain of LFE is set to –6 dB, 0 db, and +6 db. An 8^{th} order Linkwitz-Riley low-pass filter is used where the cut-off frequency is 120 Hz.

An all-pass filter is created in the APF method by summing the 8^{th} order Linkwitz-Riley low pass filter (LPF) and high pass filter (HPF) for easy realization. A delay of 7.8 ms is set in the DLY method. This delay value achieves the minimum group delay deviation proposed in [1]. The result of this simulation is shown in Fig. 6.

In the INV method (Fig. 6a), the magnitude and the phase difference indicate an evident cancellation in the lower frequency. The group delay indicates that there is some improvement as compared to the simple LPF, but it registers a big dip and a step.

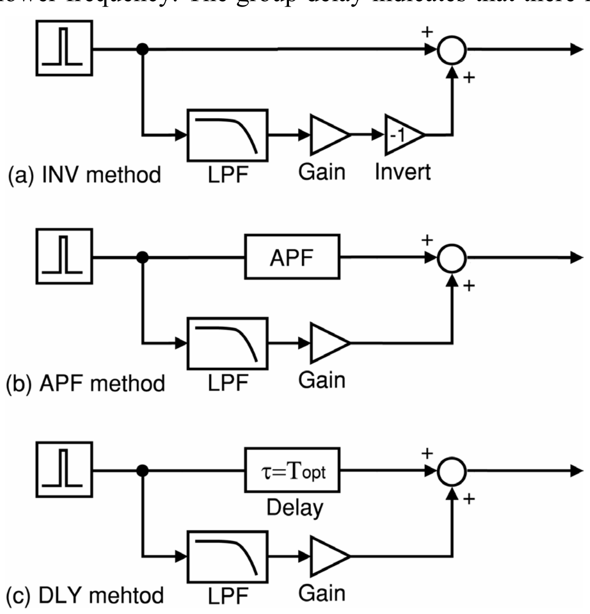

Figure 5: Block diagram of the three methods

In the APF method (Fig. 6b), phase difference indicates there is no cancellation at any frequency. However, the group delay and the impulse response of the main channel indicate that the all-pass filter alters the sound of the main channel. The group delay indicates that there is almost a 7 ms difference at the border of the cut-off frequency. This difference renders the bass sound dull and flat.

In the DLY method (Fig. 6c), the magnitude and the phase difference indicate that there is no cancellation in the pass band of the LFE. Although the phase difference is suppressed by a small value in the pass band, the phase difference is quite high above the cut-off frequency.

However, considering that the slope of the LFE is sufficiently steep (–48 dB at 240 Hz), the influence of this difference can be neglected. The group delay is also almost flat at all frequencies, except a small peak and a dip that is observed around the cut-off frequency. This implies that the reproduced LFE and the mains are almost coincident.

In this simulation, the DLY method greatly improves both the cancellation and the group delay of the summed signal. We name this method "LFE Phase Control".

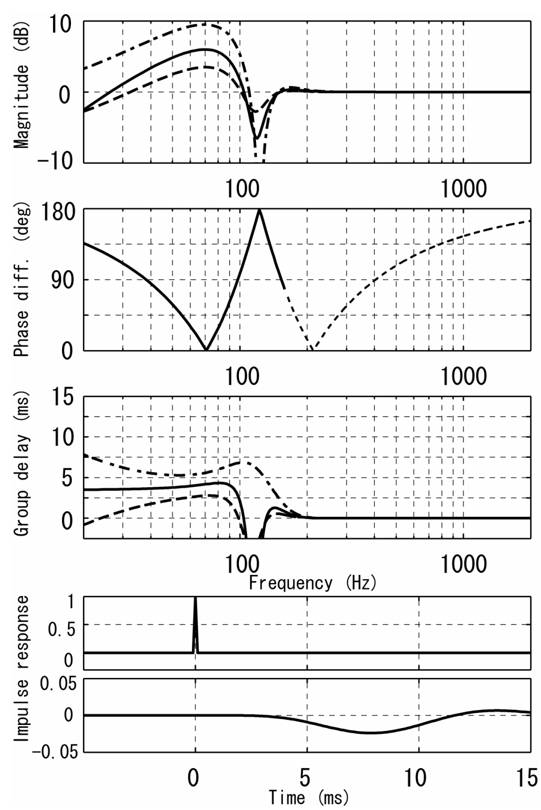

Figure 6a: Results of the INV method

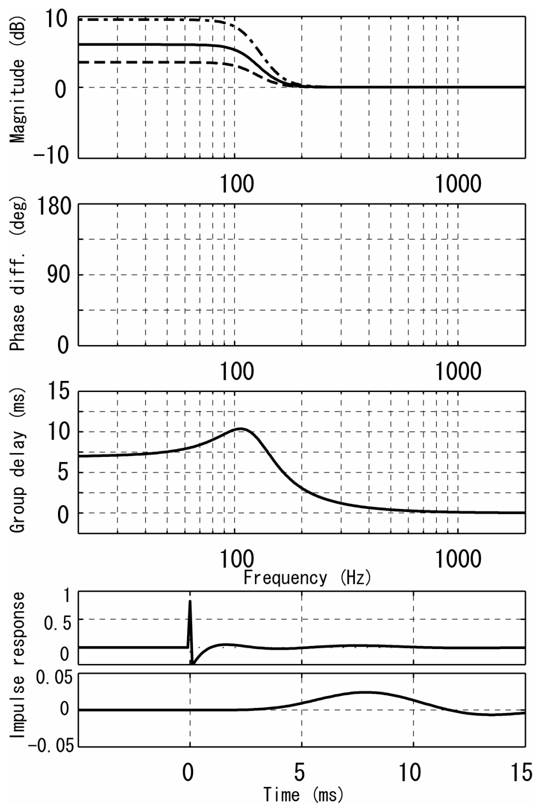

Figure 6b: Results of the APF method

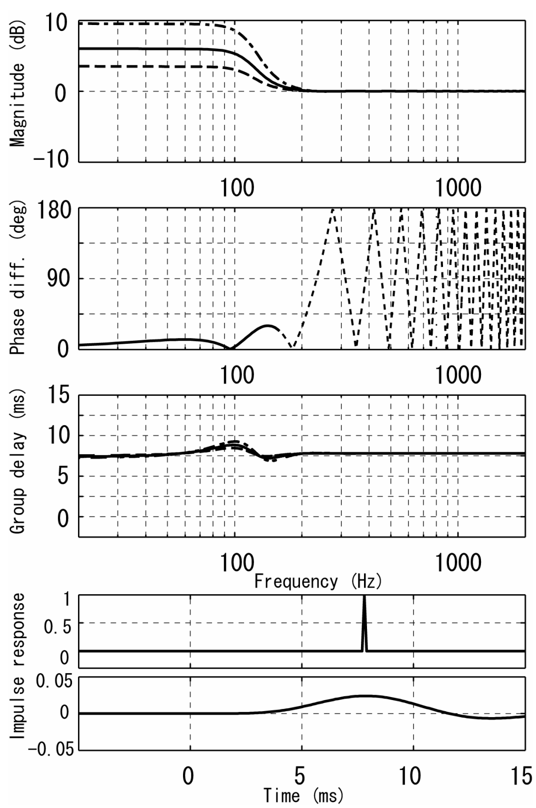

Figure 6c: Results of the DLY method (LFE phase control)

3 INFLUENCE OF ENCODER AND DECODER

In a common encoder, an LPF is used by default for the LFE channel; this is because of the bandwidth requirement of the LFE. Therefore, the process of encoding and decoding could change the matching between the LFE and the mains, even if the LFE and the mains are matched in the master source.

We briefly tested the encoder and decoder in terms of the matching of the LFE and the main channel. We compared the output of a DVD player and the master source that was created using ProTools as follows:

1. Encode the master source and author the DVD.
2. Import some part of the song from the DVD player to ProTools.
3. Align the master source and the signal from the DVD by comparing the waveform of the mains.
4. Compare the LFE between the master and the signal from the DVD in a time domain.

While creating the master source of the DVD, an LFE is created from the bass part of the center channel by using a 4th order LPF with the “LFE phase control” method.

We tested both Dolby Digital [4] and DTS [5]. DP569 (version 7.0) is used for Dolby Digital and CAE-4 (version 3.0) is used for DTS. The LPF of the encoder is turned on according to the default value.

The result is shown in Fig. 7. If there is a mismatch, caused by the coding and decoding process, the LFE of the master and the signal from the DVD is not the same; instead, it exhibits some delay in the time domain.

Fig. 7 shows both the encoders. DP569 and CAE-4 are almost identical to the master source in terms of time and phase. This result indicates that both the encoders employ some processing to align the LFE and the mains, although they use LPF in the LFE channel. This result shows that it is sufficient to consider the matching only

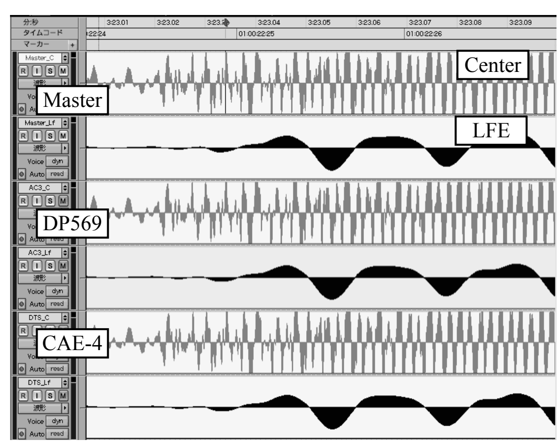

Figure 7: Influence of the codec

in the master source.

We have information that some older versions of DP569 exhibit a delay in the LFE channel when the LPF is switched on. We have not yet verified this matter, but we are planning to measure this before the conference begins. Nevertheless, we recommend upgrading to version 7.0 or later versions.

4 MONITORING ENVIRONMENT

While creating an LFE without phase mismatch issues, a monitoring environment that does not cause phase mismatch issues is required. Therefore, we describe the technique to create a monitoring environment for the accurate monitoring of the LFE and the mains.

4.1 With bass management

When a subwoofer with a bass management controller is used, the bass outputs from the main channel and the LFE are redirected to the subwoofer and summed with the LFE as shown in Fig. 8.

In most cases, the cut-off frequency of the LPF for redirecting the main channel is set to 80 Hz, and the LPF for LFE is set to 120 Hz. Thus, the phase of the LFE and the bass part of the mains that are redirected into the subwoofer are not the same. The phase difference between the LFE and the mains is shown in Fig. 9. A 4th order Linkwitz-Riley LPF is used in this case.

In Fig. 9, a phase difference of up to 60 degrees is observed. This difference is acceptable to monitor the LFE with sufficient accuracy, because a phase difference of less than 90 degrees does not produce cancellation. The Genelec subwoofer has an LFE "redirect" function that sets the LFE cut-off to 85 Hz, the same as the LPF of the mains, and any LFE with a frequency above 85 Hz is redirected to the center channel [6]. When this type of function is used, the phase mismatch between the LFE and the mains is eliminated.

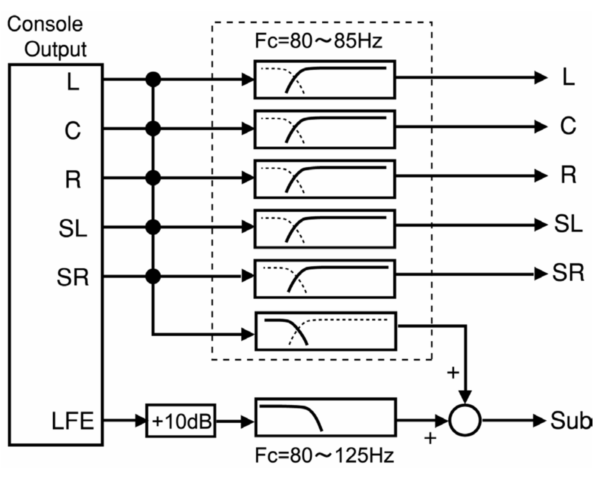

Figure 8: Block diagram of a bass management controller

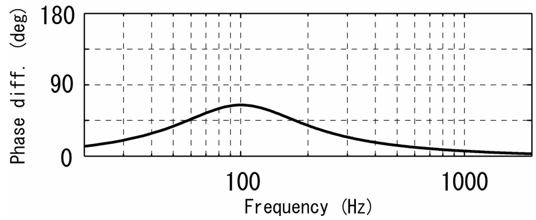

Figure 9: Phase difference between 80 Hz and 120 Hz LPF

4.2 Without bass management

When a bass management controller is not employed, a subwoofer reproduces only the LFE channel. Therefore, the time and phase matching between the main speakers and the subwoofer becomes important.

If an LPF is used in the subwoofer for simulating the response of the codecs, it is necessary to consider the fact that the codecs perform some processing to eliminate the phase mismatch as mentioned above.

We recommend inserting a delay for the main channels, as shown in Fig. 5c, to simulate the LPF of the encoder exactly. Otherwise, severe cancellation occurs. Fig. 10 shows the phase difference between unity and the 4th order Linkwitz-Riley LPF where the cut-off frequency is 120 Hz. In Fig. 10, a phase difference indicates the mains and the LFE is almost out-of phase around cut-off frequency. This makes it difficult to not only judge the sound quality correctly but also to set the appropriate LFE gain due to the cancellation around the cut-off frequency.

If LPF is already used in the master source, which is true in most cases, bypassing the LPF of the subwoofer is also a recommended solution. If LFE is already band limited in the master source, the influence of the encoder is not as significant as compared to the adverse effect of phase mismatch.

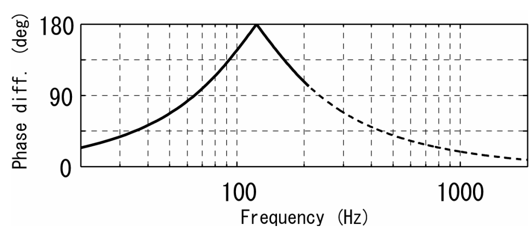

Figure 10: Phase difference between 120 Hz LPF and unity

5 REPRODUCTION OF LFE IN THE CONSUMER MARKET

We summarize the current situation from the perspective of phase mismatch of the LFE. AV receiver and subwoofer could cause the phase mismatch of LFE in reproduction in the consumer market equipment.

5.1 AV receiver

The configuration of the bass management controller in an AV receiver highly influences any initiation of a phase mismatch. When all the speakers are set to “small,” the LFE and the bass frequency that is redirected from the main channels are summed electrically with the same LPF.

Therefore, there is no possibility of a phase mismatch occurring between the LFE and the main channels.

When all the speakers are set to “large,” the use of the LPF for the LFE depends on the model of the AV receiver. Indeed, if an LPF is used for the LFE, phase mismatch will occur.

When “large” and “small” speakers are mixed in the system, phase mismatch is caused not only between the LFE and the main channel but also between the main channels.

Pioneer recently launched an AV receiver that resolves this phase mismatch by bass management, even in a mix of “large” and “small” speakers [7]. The handling of phase mismatch in AV receivers will be improved by this type of technology.

5.2 Subwoofer

Most consumer subwoofers are able to change the crossover frequency continuously. This function was originally designed for expanding the bass of the stereo speakers with directly connected speakers.

Presently, subwoofers are connected to AV receivers, so an LPF in the subwoofer is essentially not necessary. Using an LPF not only causes cancellation between the LFE and the mains but also problems with bass management.

The number of subwoofers that equip an LPF bypass function has been increasing, and roughly half the number of subwoofers equips it now.

5.3 Home Theater in a Box

Most home theatres in a Box (HTiBs) generally consist of five small satellites, a subwoofer, and a receiver. In this type of product, all the bass sounds from the main channel are redirected to the subwoofer with proper bass management. Therefore, the phase mismatch between the LFE and the mains does not occur in HTiB. Fortunately, many consumers are using this type of a product, which does not have the phase mismatch problem.

6 SOME EXAMPLES IN ACTUAL RECORDING

We introduce some examples for creating an LFE without the phase mismatch problem using ProTools [8].

6.1 Using a delay plug-in

First, we introduce a method that uses a delay plug-in incorporated in the master fader for compensating the delay caused by the LPF (Fig. 11).

1. Insert a filter plug-in into the 5.1 ch master fader and apply the LPF for LFE.

The slope and the cut-off frequency of the filter should be known. In this example, we use “FilterBank F1” and the slope is set to –24 dB/oct and the cut-off is set to 80 Hz. Unlink the channels and set all the channels other than LFE to “Bypass.”

2. Insert the delay plug-in into the master fader; apply the delay to all channels other than the LFE.

The “time adjuster medium” is used in this example. Input the optimum delay by referring the optimum delay table (Appendix I).

However, this method may cause a lip-sync problem; therefore, the sync point for time code should be properly adjusted.

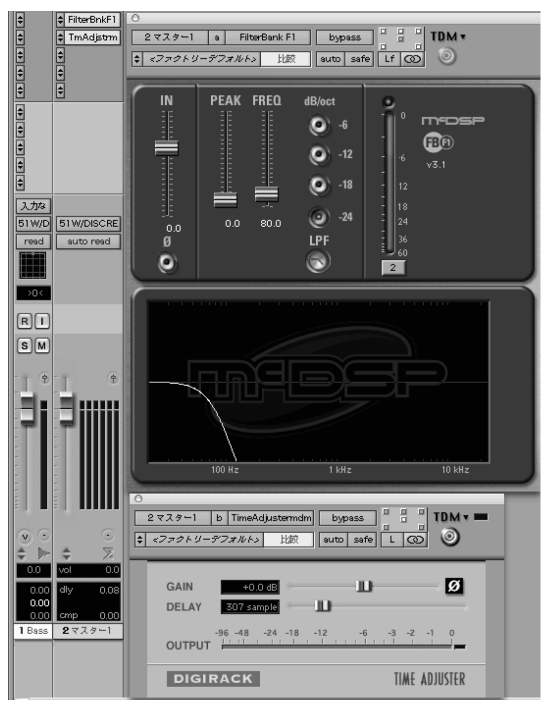

Figure 11: An example of using the delay plug-in

6.2 Method of duplicating the LFE

Next, we introduce a method that can use multiple types of LPFs in one project without changing the main channel. In this method, no modifications are made to the master fader, the LPF is applied individually, and the time is adjusted.

1. Duplicate the track used for the LFE.
2. The former track is set to be sent to a 5.0 surround path, and the latter track is set to be sent to an LFE path.
3. Apply the LPF to the track that is sent to the LFE path.
4. Referring to the optimum delay table, move the region back.

These methods can be applied in other DAWs by almost the same procedure.

7 TESTING PHASE MATCHING

In stereo recordings, the phase mismatch between the left and right channels can be easily judged by ear. But phase mismatch between the LFE and the mains is not always easy, because of monitoring environment issues.

In this situation, an objective tool to test the matching of the LFE and the main channel is useful. We introduce some tips and a tool to test phase matching of master source.

7.1 Observing the waveform

Observing the waveforms of the LFE and the mains is the easiest method to check for any phase mismatch. First, search the "solo" part. Second, compare the first peak of the mains and the LFE in percussion sounds, as shown in Fig. 4.

It is easy to know the lag in the time domain in percussion sounds, but in sounds containing a higher order of harmonics like strings, the lag in the time domain is difficult to judge by just comparing the waveform. Apply the same LPF to both the LFE and the mains. This method is simple, but quite troublesome for searching the "solo" part.

7.2 Using SmaartLive

We introduce the method of using SmaartLive, which does not require the manual searching of the "solo" part.

1. Connect the output of ProTools or a DVD player to the line input of a PC, one is from the LFE and the other is from one of the main channels.
2. Set up SmaartLive as shown in Fig. 12.

Set the measurement mode to the "Transfer function mode" and activate the phase display. The "coherence blanking" feature eliminates the effect of other instruments; it measures only the instrument that is used in the LFE. It is recommended to set the "coherence threshold" value to 20% or greater for a stable measurement.

3. Begin the measurement, play back the source, and observe the "phase" display.

The "phase" display indicates the phase difference between the LFE and the main channel.

Fig. 13 provides two examples of measurements in SmaartLive. In these examples, the same source as shown in Fig. 2 is used for Fig. 13a. Fig.13a evidently indicates that the cancellation occurs. At around 63 Hz, the mains and the LFE is completely out of phase. The source for Fig. 13b and the timing of LFE are adjusted to match the peak value of both the LFE and the center channel. Fig. 13b indicates that the reduction in the phase difference much improves over the original.

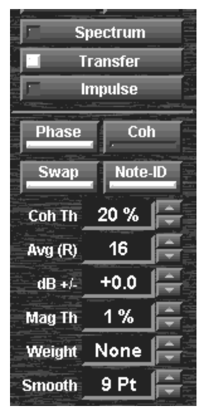

Figure 12: Measurement setup in SmaartLive

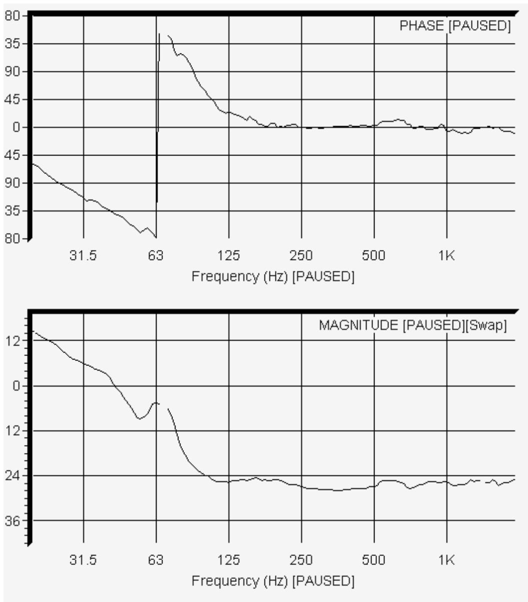

Fig. 13a: Measurement example in SmaartLive (The case where phase Mismatch occurs)

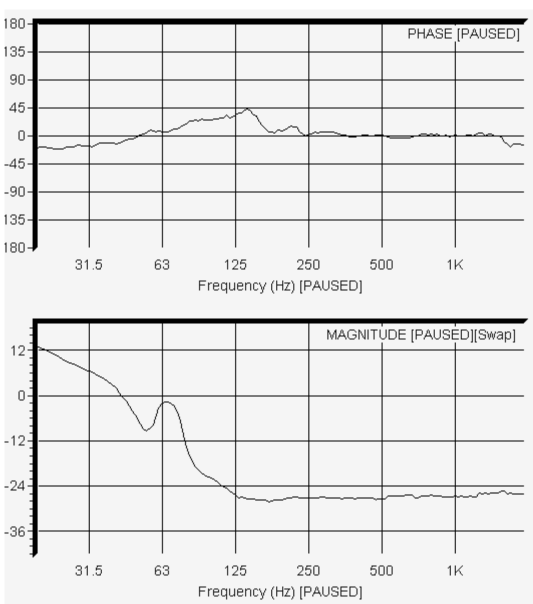

Fig.13b: Measurement example in SmaartLive (The case where phase mismatch does not occur)

8 CONCLUSIONS

It can be said that the matching of time and phase between the LFE and the mains is as significant as matching of the main channels.

We hope that this study encourages a wide discussion on LFE and leads to the positive use of LFE.

REFERENCES

[1] S. Hosoi, H. Hamada and N. Kameyama, “An Improvement in Sound Quality of LFE by Flattening Group Delay”, Proc. of 116th Audio Eng. Soc. Conf., preprint 6115 (2004).

[2] ITU-R BS.775-1 “Multichannel stereophonic sound system with and without accompanying picture”, International Telecommunications Union, Geneva, 1994.

[3] SIA Software, www.siasoft.com

[4] Dolby Laboratories Inc., www.dolby.com

[5] Digital Theater Systems, www.dtsonline.com

[6] Genelec Oy, www.genelec.com

[7] Pioneer Corporation, www.pioneerelectronics.com

[8] Digidesign Inc., www.digidesign.com

Optimum Delay Table for LFE Phase Control (in ms)

	Butterworth						Linkwitz-Riley			
	–6 dB/oct 1st	–12 dB/oct 2nd	–18 dB/oct 3rd	–24 dB/oct 4th	–36 dB/oct 6th	– 48dB/oct 8th	–12 dB/oct 2nd	–24 dB/oct 4th	–36 dB/oct 6th	–48 dB/oct 8th
63 Hz	0.8	3.7	6.1	8.2	11.3	15.8	3.1	8.2	12.1	15.8
80 Hz	0.7	2.9	4.8	6.4	9.6	12.4	2.6	6.4	9.5	12.4
100 Hz	0.6	2.3	3.8	5.1	7.5	9.9	2.1	5.1	7.5	9.8
125 Hz	0.5	1.9	3.0	4.1	6.0	7.9	1.7	4.1	6.0	7.8
160 Hz	0.4	1.4	2.3	3.2	4.7	6.1	1.4	3.2	4.7	6.1

Optimum Delay Table for LFE Phase Control (in samples fs = 48 kHz)

	Butterworth						Linkwitz-Riley			
	–6 dB/oct 1st	–12 dB/oct 2nd	–18 dB/oct 3rd	–24 dB/oct 4th	–36 dB/oct 6th	–48 dB/oct 8th	–12 dB/oct 2nd	–24 dB/oct 4th	–36 dB/oct 6th	–48 dB/oct 8th
63 Hz	38	178	293	394	542	758	149	394	581	758
80 Hz	34	139	230	307	461	595	125	307	456	595
100 Hz	29	110	182	245	360	475	101	245	360	470
125 Hz	24	91	144	197	288	379	82	197	288	374
160 Hz	19	67	110	154	226	293	67	154	226	293

Optimum Delay Table for LFE Phase Control (in samples fs = 96 kHz)

	Butterworth						Linkwitz-Riley			
	–6 dB/oct 1st	–12 dB/oct 2nd	–18 dB/oct 3rd	–24 dB/oct 4th	–36 dB/oct 6th	–48 dB/oct 8th	–12 dB/oct 2nd	–24 dB/oct 4th	–36 dB/oct 6th	–48 dB/oct 8th
63 Hz	77	355	586	787	1085	1517	298	787	1162	1517
80 Hz	67	278	461	614	922	1190	250	614	912	1190
100 Hz	58	221	365	490	720	950	202	490	720	941
125 Hz	48	182	288	394	576	758	163	394	576	749
160 Hz	38	134	221	307	451	586	134	307	451	586

Appendix I: Optimum delay table for LFE phase control