Reproducing Commercial Multichannel Formats Through a Single Monitoring System

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Abstract

A modern audio production facility must be able to supply productions in a large number of different formats. The change from mono & stereo to multi-channel reproduction has created many problems, both in converting existing production facilities to multichannel format and when building new installations. This paper examines the LFE channel across different encoding formats and presents a method to reproduce it, using a bass management system, through a single monitoring system.

Introduction

Today, a modern audio production facility must be able to serve productions in a large number of different formats. The change from mono and stereo to multichannel reproduction has produced many problems, both in converting existing production facilities to multichannel format and in new installations. The audio formats that must be handled by a modern production facility currently include mono, stereo, matrix four channel formats, five 5.0 systems, 5 channel systems with a separate Low Frequency Enhancement channel (5.1 systems) and advanced multichannel formats such as 6.1 and 7.1. This paper presents a brief overview of the current multichannel formats and a hardware solution to reproduce all these formats using a single loudspeaker system.

Loudspeaker set-up for multichannel audio

The ITU that issues many recommendations for various application areas, and offers two recommendations that are of particular interest for surround sound reproduction: ITU–R BS.775–1 [1] and ITU–R BS 1116–1 [2]. The following sections highlight the most important points of these recommendations with regard to the LFE channel and subwoofer.

Placement of the subwoofer in the room

Psychoacoustics research work has shown over the years that the very lowest frequencies have minimal audible stereophonic effect and hence may be reproduced by a single source [3, 4]. However, in some relatively recent, but uncorroborated, research [5], it is suggested that for best psychoacoustic perception results

(spaciousness and envelopment), there should be two subwoofers placed on either side of the room and driven with the same signal but with a 90° phase difference between them.

A commonly recommended place for the subwoofer is at the front of the room, on the floor and in the middle, equidistant from the sidewalls. This position can be a serious compromise since the subwoofer sits in the pressure minimum of the odd numbered lateral standing waves. To overcome this, the subwoofer can be slightly offset from the middle of the room or placed in one of the front corners. The second option maximises the system efficiency due to corner loading but risks the increased probability of localisation. Gain (input sensitivity) and frequency response (bass roll-off) adjustment of the subwoofer is necessary since the acoustical loading has changed relative to calibrated anechoic conditions. The subwoofer can also be flush mounted in the front wall but the discussion of the position of the source relative to the room remains valid. The phase adjustment on the subwoofer at the crossover frequency is also important to achieve a flat frequency response around the crossover region.

Sometimes the rear loudspeakers also need additional low frequency extension. There are two options. Firstly, a bass management system can include the rear channels as inputs and so the low frequency content will be reproduced through the subwoofer(s). In this case, it is important that all satellite loudspeakers are placed on the circle radius so that the arrival time difference between each loudspeaker and the subwoofer is the same. It must be also noted that the acoustical behaviour of the room at low frequency will greatly affect the way the low frequencies are summed and replayed by a single subwoofer. In this case, the low frequency acoustical characteristic of the room should be as identical as possible in the front and in the rear part of the room. Alternatively, a separate subwoofer can be used for the rear loudspeakers. The location of this subwoofer should be to the rear of the room and positioned in a similar fashion to the subwoofer for the front channels. If the room has very different low frequency acoustical characteristics from the front to the back, the option of dual subwoofers might provide better results than using only a single subwoofer.

The LFE channel

What is the LFE (.1) channel?

Often the LFE channel is referred to as the *'subwoofer channel.'* In fact, the LFE channel is the space on the recording medium for the .1 encoded, band limited audio channel. The *'subwoofer channel'* is not a *'channel'* as such, as the subwoofer, together with the bass management system [6, 7], replays a specific low frequency bandwidth. The subwoofer signal may consist of some, or all, of the LFE channel and possibly the low frequencies of the main channels if bass management is used and depending on how the system is set-up.

In a 5.1 surround sound system, the five main channels (Left, Centre, Right, Rear Left and Rear Right) are all full bandwidth, i.e. <20 Hz to >20 kHz. Before encoding, the LFE channel is not band limited, i.e. it is just another full bandwidth channel. Once encoded, the LFE channel has a limited bandwidth (hence the slightly misleading label '.1') from <20 Hz up to various upper cut-off frequencies depending on the encoding format (Figure 1 and Table 1).

Encoding Formats	LFE Upper Cut-off Specifications
Dolby Digital (AC-3, 5.1)	120Hz, fixed cut-off [9]
Dolby EX (AC-3, 6.1)	120Hz, fixed cut-off [9]
DTS (Coherent Acoustics, 5.1)	120Hz, nominal [10]
DTS-ES (Coherent Acoustics, 6.1)	120Hz, nominal [10]
DVD-Audio (MLP)	Full bandwidth channel [11]
Super Audio CD (Sony/Philips)	Full bandwidth channel [12]
MPEG-2 BC (ISO/IEC 13818-3)	Most likely variable? [13]
AAC MPEG-2 (ISO/IEC 13818-7)	Variable, up to 1kHz [14]
Sony Dynamic Digital Sound (7.1)	Variable up to 330Hz [15]

Table 1: LFE channel bandwidths

The use of the LFE channel is not consistent throughout the audio industry, as the needs of movie theatres (cinemas), home theatres and digital broadcasting (DVB & DAB) are all different. Also, sound engineers new to multichannel surround sound mixing are still experimenting with new ideas and techniques. In general, regardless of the obvious benefits of the low frequency extension, the use of subwoofer(s) and reproduction of the LFE channel is currently causing many problems. These should be overcome with proper bass management circuitry and more clearly defined standard practices of the use of the LFE channel [8].

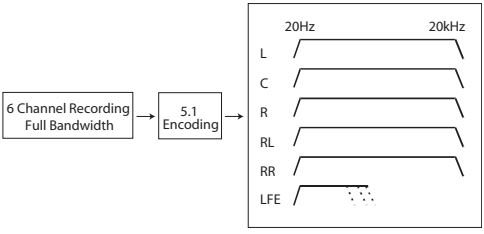

Figure 1: Audio bandwidth of encoded 5.1 Materials

Headroom in the LFE channel [6, 7]

If the LFE channel is recorded at the same nominal level as the all the main channels then a high SPL effect could easily overload the recording medium. This would defeat the object of having a special channel for loud sound effects as the main channels would have to be recorded at a lower level to accommodate the 'big bangs' on the LFE channel. To overcome this problem some encoding systems require the LFE channel to be monitored with an in-band gain of +10 dB. In doing so, the audio level recorded to tape will have an additional 10 dB of available headroom as the engineer will naturally reduce the level by 10 dB on the mixing consol to maintain the sound level balance between the channels. Note that this increase in headroom is at expense of 10 dB of signal-to-noise ratio but as the LFE channel is eventually band limited in the encoder, it is considered to be a price worth paying.

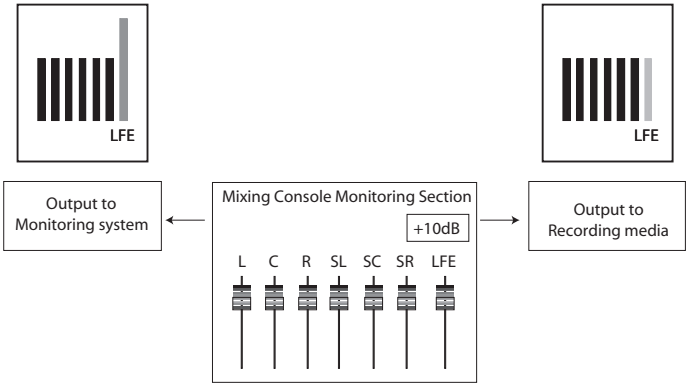

Figure 2: +10dB Level change in the LFE channel

To monitor the LFE channel correctly, there must be a +10 dB level change somewhere between the LFE channel fader and the acoustic output of the monitoring system (Figure 2). This level change can happen at various places in the audio chain, but it must be implemented during the production stage. Note that there are no level changes on any of the outputs to the tape or hard disk recorder. The net effect is that there is 10 dB additional headroom on the LFE channel on the tape compared to the main channels. All the tracks are then encoded using various encoding schemes, transported to the end user and replayed accordingly using a +10 dB gain stage on the LFE channel only to restore the channel balance.

Implications for monitoring of the LFE channel audio content

As stated in various standards, the LFE channel was originally intended to carry signals that are not included in the main channels [8, 16]. In the movie industry, engineers use the LFE channel to reproduce special low frequency effects, however, the practical use of the LFE channel is open to many possibilities.

As there are six (or more) channels to be replayed, it may seem logical to connect each output of the multichannel source directly to the appropriately positioned loudspeakers and to the subwoofer(s). However, without taking care that the entire bandwidth of each channel is properly monitored with bass management or redirecting some of the LFE channel correctly, important parts of the audio bandwidth are not reproduced or serious cancellation effects can be induced, both electrically and acoustically.

Firstly, unless they are full bandwidth, each loudspeaker replaying the five or six main channels will have a –3 dB LF cut-off that is higher than 20 Hz. Therefore, the lowest frequencies of the main channels will not be reproduced and monitored. This is a compromise as all the main channels are full bandwidth even after an encode/decode cycle.

Secondly, the subwoofers considered later in this paper have a crossover point fixed at 85 Hz. Research has found that, after many investigations and subjective listening tests [3, 4], a fixed 85 Hz frequency has been chosen for best acoustical results. If the encoded LFE channel is connected to the subwoofer and the main loudspeakers are

not connected via the subwoofer, audio material up to 85 Hz only will be monitored via the subwoofer. No information above that frequency will be heard, even though the LFE upper cut off can be higher.

Bass management

What is bass management?

In stereo reproduction, signals from 20 Hz to 20 kHz need to be replayed and good quality multi-way loudspeaker systems can reproduce that bandwidth fairly evenly. In multichannel audio, professional and consumer applications must be able to reproduce all frequencies from each channel. To achieve this, the main loudspeakers, subwoofers and crossovers should work together to give a flat response for each channel.

In small rooms with basic acoustic treatment and geometry, the frequency response of a loudspeaker system below 100 Hz is dominated by the modal response of the room, especially if it has parallel walls. Therefore, it is very difficult to achieve a consistent low frequency response from multiple full-range loudspeakers in such a compromised space. One solution to this basic acoustical problem is to employ a system called 'Bass Management' [6, 7]. Using active electronic filtering, the low frequency information from the main channels can be extracted and routed to a single subwoofer feed. The low frequencies now originate from a single source that can be placed in an optimum position in the room. Furthermore, the LFE channel can also be monitored using the subwoofer by adding it to the low frequencies of the other main channels. Therefore, the Bass Management's goal can be summarised as, 'To ensure that the entire audio bandwidth of all channels is accurately monitored.'

In their recommendations [8], Dolby Laboratories say that, 'Bass Management allows the user to redirect low-frequency information from any of the main loudspeakers to the subwoofer'. In addition [6, 7], Tomlinson Holman of TMH Laboratories says that, 'Bass Management in monitoring can be used to reproduce both the very low frequency content of the main channels, as well as the LFE channel, over one or more subwoofers.'

If the multichannel set-up uses small or mid sized monitors, then a subwoofer should be included to extend the frequency response of all of the main channels and to correctly monitor the LFE channel. The low frequency cut-off of the subwoofer in the room should be <20 Hz and the low pass filter of the subwoofer crossover should be very steep so that midrange information is sufficiently attenuated. For the subwoofer bandwidth, a fixed crossover point has been carefully chosen to be 85 Hz to minimise the possibility of localisation of the subwoofer. This means that for the bass management of the six main channels, the crossover point between the subwoofer and the main channels is set at 85 Hz.

Looking at the LFE channel after encoding, it can be seen that the upper cut-off frequency can vary quite significantly. For that reason, the Bass Management should provide three different setting possibilities for reproducing the LFE channel. The setting of the LFE channel bandwidth on the subwoofer should not at all affect the encoding of the LFE channel in the various formats but should provide different replay bandwidths.

Example of a 6.1 bass management system

An example of a bass management system can be seen in the 7000 Series Subwoofers manufactured by Genelec Oy [17]. The active electronics of the subwoofer are combined with the bass management section thereby offering a versatile system. The integrated 6.1 bass management system features:

- Six main channels of inputs & outputs are provided for low frequency redirection. Each channel is identical and has a fixed crossover frequency set at 85 Hz.
- Bass management bypass function for the six main channels. The LFE channel is not affected by the bypass function, regardless of the LFE bandwidth and redirection settings.
- Discrete LFE input with user-selectable reproduction bandwidth with an upper cut-off at 85 Hz or 120 Hz.
- Possibility to redirect the LFE information above 85 Hz to the Centre channel when the bandwidth is set to 85 Hz.
- Selectable +10 dB LFE gain for the LFE channel.
- Possibility to add more subwoofers to the system for increased SPL and headroom.
- Indication of clipping and driver protection activation.
- 90° step phase adjustment at 85 Hz crossover frequency between the subwoofer and the main loudspeakers. Built-in 85 Hz test tone generator tool for easy on-site adjustment.
- Frequency response adjustment, Bass Roll-off: 0 dB, –2 dB, –4 dB and –6 dB.
- Variable input sensitivity from –6 dBu to +12 dBu (=100 dB SPL at 1 m).

The correct connection of the system is shown in Figure 3. All channels, including the LFE channel, are connected through the bass management system with the six main channels connected to each of the main loudspeakers. A single output from the master subwoofer (Sum Out) is fed into the optional slave subwoofer unit (Sum In).

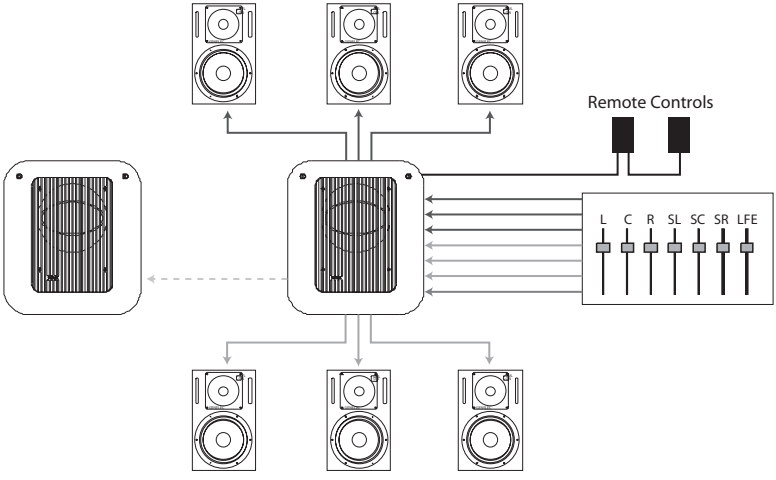

Figure 3: Connection to the 6.1 bass management system

Full range LFE input

The first possibility for the LFE channel bandwidth is the reproduction of the LFE channel by the subwoofer up to 85 Hz and then the redirection of the energy above 85 Hz to the Centre channel. This means that all information present on the LFE channel will be reproduced through the loudspeaker system, whatever the upper cut-off frequency of the LFE channel (Figure 4). Any noise, distortion artefacts and other unwanted sounds on the LFE channel can be monitored in addition to the LFE signal itself.

In addition, any type of LFE content (coherent or non-coherent audio material) will be properly monitored without unpredictable summing of the low frequencies between the different channels in the room. This should be the default setting for the bass management system as it gives full range monitoring of the LFE channel.

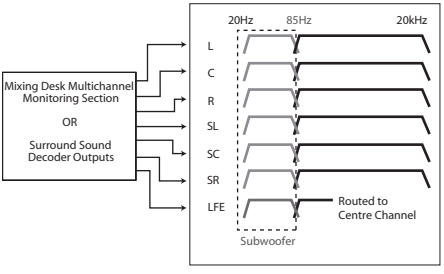

Figure 4: Redirection of LFE channel above 85Hz to centre channel

LFE input band-limited to 85 Hz

The second possibility for the LFE channel bandwidth is the reproduction of the LFE channel by the subwoofer up to 85 Hz, without any redirection above 85 Hz to the Centre channel. This setting is comparable to pre-filtering the LFE channel in the mixing console using an 80 Hz LP filter [16]. No information above 85 Hz present on the LFE channel will be heard through the loudspeaker system (Figure 5). This setting is not recommend for normal everyday use as the LFE channel has a frequency response up to 120 Hz in Dolby Digital & DTS and a higher frequency response still on some of the other formats. A good use for this setting is to simulate the side effect of some (usually cheaper) consumer decoders that, when the bass management is used, do not replay the information on the LFE channel that is above 80 Hz. It is important for the mixing engineer to be aware of such a limitation so that the multichannel mix translates well in the home environment. This configuration provides a replica of what will happen in many home surround system situations and yields a consistent reproduction of the low frequencies below 85 Hz.

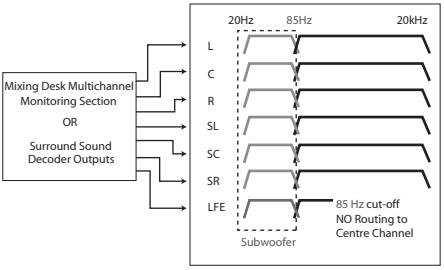

Figure 5: LFE input band-limited to 85Hz

LFE input band-limited to 120 Hz

The third possibility for the LFE channel bandwidth is the reproduction of the LFE channel by the subwoofer up to 120 Hz without any redirection above that frequency. This means that no information above 120 Hz on the LFE channel will be heard through the loudspeaker system (Figure 6). This setting has been provided so that the production facility can emulate the replay systems that exist in movie theatres and cinemas. In this application, there are strict rules on how the replay system should perform [16]. Dedicated subwoofers with a frequency response from 20–120 Hz reproduce the low frequency content for the 35 mm movie soundtracks. However, it must be noted that when mixing music and sound effects for film release, engineers always use non-coherent low frequency information in the LFE channel compared to the main channels. In other words, the low frequency LFE channel content is different from any other main channel low frequency audio content so that potentially unpredictable acoustic summing in the room is avoided.

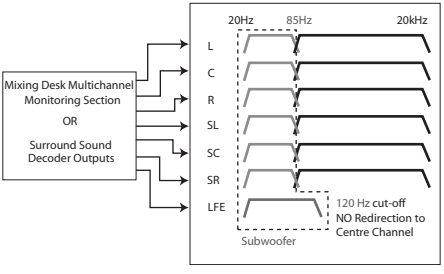

Figure 6: LFE input band-limited to 120 Hz

Bass management bypass function

The LFE channel is unaffected by the bypass function as it affects the main channels only. This means that the low frequency extension of all main channels provided by the subwoofer is bypassed and the main loudspeakers monitor the full bandwidth of each of the main channels. The low frequency reproduction of the main channels will extend as low as the main loudspeaker low frequency extension. The LFE input is not changed in any way and hence LFE bandwidth and routing settings are not affected (Figure 7).

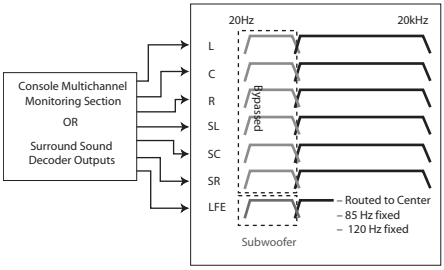

Figure 7: Main channels bypassed, LFE channel unchanged

Monitoring the LFE channel with full range loudspeakers

Some music recording engineers would rather not use subwoofers as they prefer to use 'full bandwidth' loudspeakers only. The argument is, for example, that in a real orchestra performance all the low frequency information does not come from one physical point in space and that the harmonic content and various reflections in the hall guide our spatial cues towards different places for the instruments in the orchestra. Other engineers in the audio post-production and movie industry sectors want to use subwoofers to reproduce the LFE channel only. In doing so, they emulate the replay conditions found in movie theatres. In that situation, the audio content of the LFE channel has to be carefully considered as cancellations may occur between the audio replayed by the main channels and by the subwoofer.

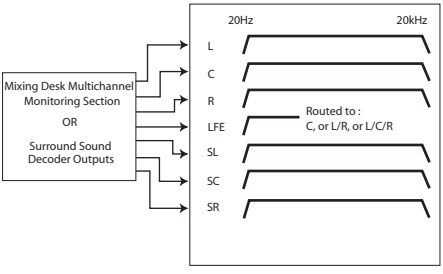

Figure 8: Re-routing the LFE to full range loudspeakers

Whatever the opinions are, it is possible to monitor accurately all the channels without a subwoofer when using multiple large full range loudspeakers. The important point is to be able to monitor each channel in its full bandwidth. Therefore, in this case, the five or six full range loudspeakers will reproduce the five or six main channels and the LFE channel should be monitored via one, or more, of the full range loudspeakers. Re-routing is required and can be done inside the mixing desk's multichannel monitoring section or in a separate multichannel loudspeaker controller (Figure 8).

The most widely used and simplest routing for redirecting the LFE channel is to send it to the Centre channel. There are other set-ups where the LFE channel is redirected to Front Left and Front Right loudspeakers (note that consumer and

professional decoders do this if there is no subwoofer in the system) or even to all three front loudspeakers (remembering the +10 dB LFE nominal level relative to main channels, this is acoustically the best solution for SPL reasons). Note that when routing the LFE channel to more than one loudspeaker, the total SPL reproduction level of that channel increases. For example, routing the LFE to the Front Left and Front Right loudspeakers will add 6 dB SPL to the overall LFE channel level, therefore, the output level of the LFE channel should be reduced accordingly in the console monitoring matrix output. The LFE channel +10 dB gain also should be summed into this equation.

Conclusions

This paper has described the LFE channel, especially its gain relative to the main channels and its upper cut off frequency in different multichannel formats. The constraints of physical subwoofers and the LFE channel were discussed and a method that overcomes these constraints, called bass management, was described. The handling of the LFE channel was given particular focus with reference to different operating methods in different industries and redirection of some or all of the LFE content to different loudspeakers. The system presented is compatible with mono, two channel stereo, all matrix formats and discrete multichannel formats up to 6.1.

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