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**Use of the low frequency effects (LFE) channel in  
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#### **Abstract**

Digital compression systems currently used for broadcasting surround sound for television include an extra audio channel specifically for the purpose of carrying high level, low frequency sound effects. This channel is commonly referred to as the "LFE". There is some debate about its usefulness in normal broadcasting, and there is much confusion about how it should be used, particularly when the concept of a sub-woofer is brought into the system.

The purpose and properties of the LFE channel found in broadcast systems are described, in isolation from sub-woofers. The addition of a sub-woofer to an audio system, without reference to LFE is also described. Ways in which the two can be combined in a single system are then shown, highlighting the numerous ways in which this can be done incorrectly. Some of the problems that make it difficult for the audience to ensure that their system is working optimally are shown.

The conclusion drawn is that use of the LFE should be limited, if it is used at all.

**Additional key words:** bass management, Dolby Digital, AC3, 5.1, low frequency enhancement channel

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## Use of the low-frequency effects (LFE) channel in broadcasting

Andrew Mason

### 1 Introduction

Digital compression systems currently used for the broadcast of surround sound for television <sup>[1,2]</sup> include an extra audio channel specifically for the purpose of carrying high level, low frequency sound effects. This channel is the “.1” in “5.1” also called the LFE (low-frequency effects, or enhancement) channel.

There is often considerable misunderstanding about the use of the “.1” in surround sound, and how it relates to sub-woofers. This paper clarifies the differences between the two and describes some of the mistakes that can arise in audio systems as a result of incomplete understanding of their rôles.

As a result of the range of ways in which the use of an LFE channel can be seen to go wrong, and the very limited justification for its use in broadcast audio, it is concluded that, in general, it is better that the “.1” channel not be used.

#### What is a sub-woofer?

A loudspeaker often contains two drive units:

The tweeter reproduces high frequencies;

The woofer reproduces low frequencies.

The purpose of a sub-woofer is to extend to lower frequencies the response of a loudspeaker. A sub-woofer may be added to reproduce frequencies that are below the capabilities of the woofer.

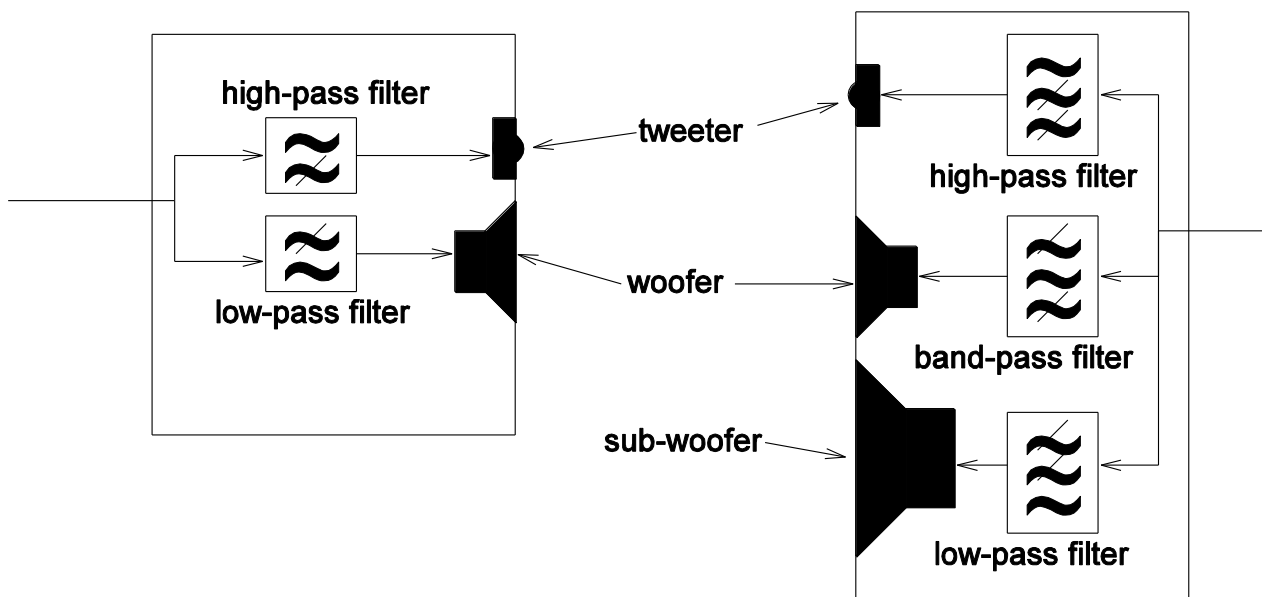


Figure 1: two-way and three-way loudspeakers with internal cross-over filters

Because low frequencies are less directional than high frequencies, it is practicable to use a single, separate, sub-woofer for a multi-loudspeaker set. There is now a wide selection of loudspeaker systems on the market where the main loudspeakers are rather small, with limited low-frequency

output, and so the overall performance is dependent on the inclusion, in the system, of a separate sub-woofer unit.

### What is the LFE?

The low frequency effects channel is most commonly encountered in Dolby Digital as the “.1” in “5.1”, although it is also present in some other audio systems. The purpose of the Dolby Digital low-frequency effects channel, (the LFE, or “0.1”), is to provide a channel for loud effects that would otherwise overload a normal channel. There are two characteristics of the LFE that suit this use: it has a limited bandwidth, of only 120Hz, and it has 10dB of gain applied on reproduction. Note that the normal channels in Dolby Digital are full band-width (from DC to half sampling rate), so the LFE is simply there to provide that 10dB gain for a limited range of frequencies.

Although LFE stands for “low frequency effects” in Dolby Digital, in other standards it is described as “low frequency enhancement”. Because of the design features of multi-channel audio systems, and the fact that the LFE channel is very often discarded by decoders, it is better to think of it only as an enhancement – and definitely not as an essential component. More on this later.

## 2 Using a sub-woofer to extend frequency range

Because basic physics limits the low-frequency performance of loudspeakers – the bigger, the better – it is useful to be able to use a single big loudspeaker to reproduce low frequencies, in combination with several smaller loudspeakers to reproduce higher frequencies (where there is spatial information). Figure 2 shows the steps required to add a sub-woofer. Two channels are shown, to reduce the complexity of the drawing, but the same principle applies to more channels.

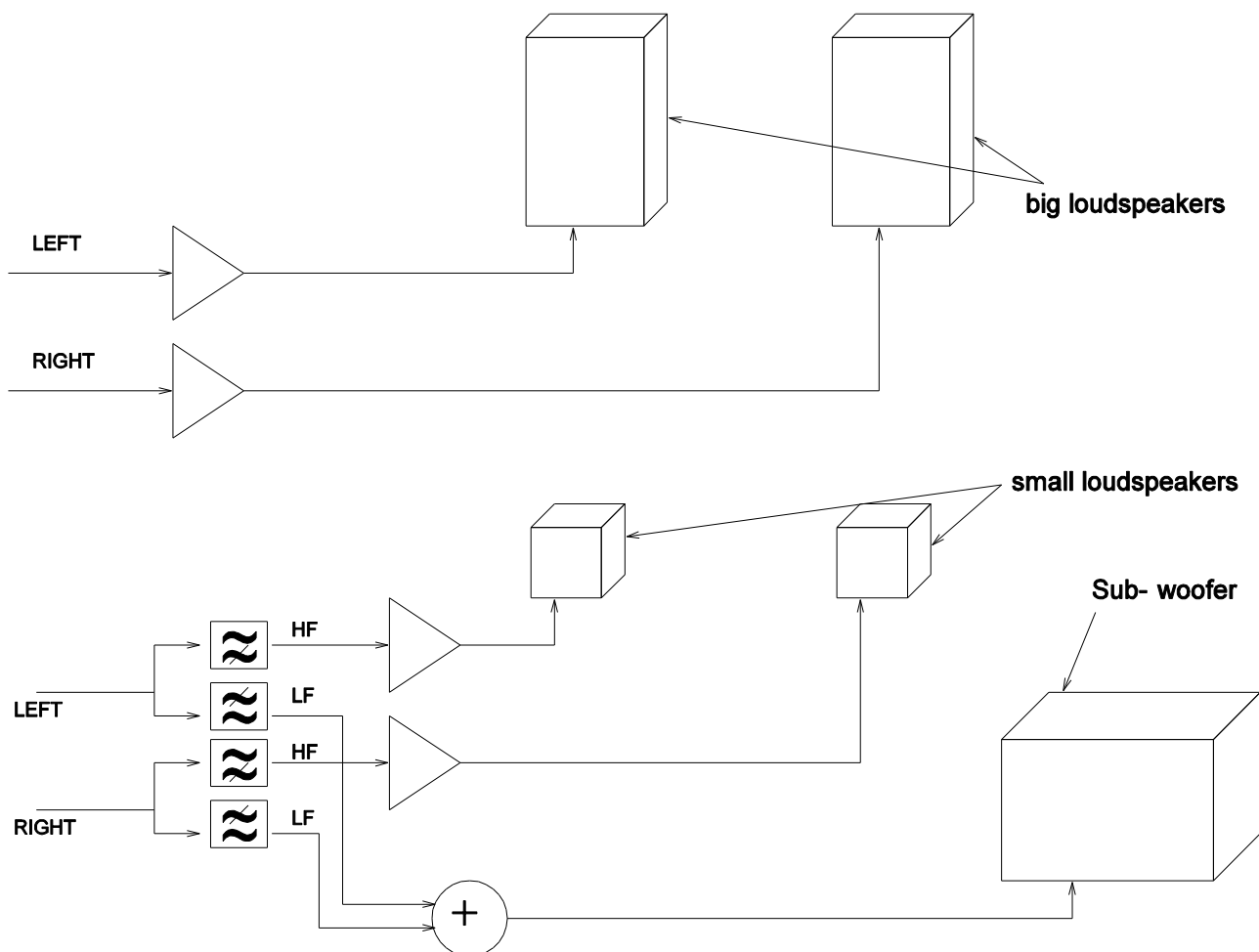


Figure 2: Addition of sub-woofer to reproduce low frequencies with small loudspeakers

In the upper part of the figure, we simply connect two large loudspeakers to the left and right signals. The lower part of the figure shows how we can reduce the size of the main loudspeakers and still get good low-frequency response by filtering high and low frequency components of the left and right signals. The high frequencies (HF) of the left and right channels are sent to their respective loudspeakers. The low frequencies (LF) of the left and right channels are combined and sent to the sub-woofer.

Optimum performance of such a combination requires careful matching of the filters to the frequency response of the loudspeakers and the sub-woofer, and careful matching of the level of the main loudspeakers to that of the sub-woofer.

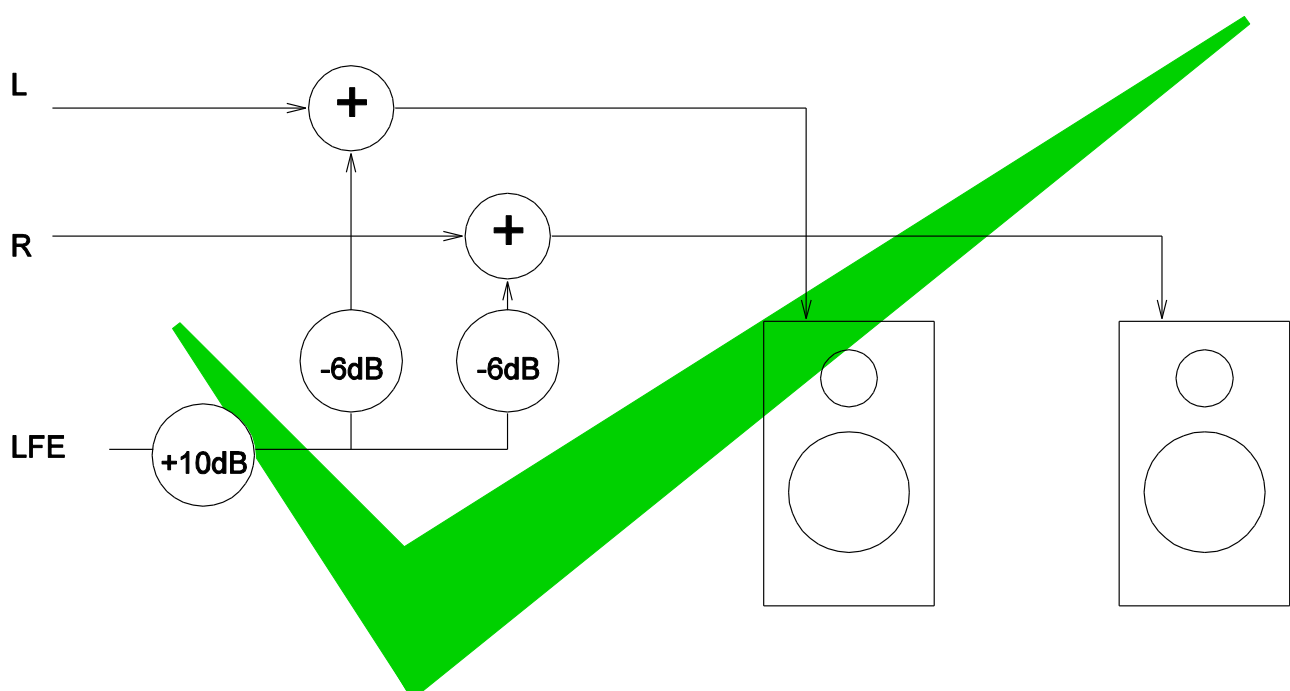
This process of filtering and signal routing is commonly referred to as “bass management” or “bass redirection”. The function may be provided by a separate functional unit (by which I mean, “box”), or may be physically incorporated into the sub-woofer unit. Some domestic products control the configuration of a built-in bass management system according to simple system settings made by the user to indicate that they have connected “small loudspeakers” or “big loudspeakers”. Amplifiers can detect whether a sub-woofer has been connected in addition to main loudspeakers. The most advanced systems can automatically adjust their operation by having a microphone connected then generating and measuring test signals.

Note that the use of a sub-woofer is entirely at the choice of, and under the control of, the listener.

### 3 Using the LFE channel to make an impact

Extremely loud, low frequencies are typical of big things exploding, erupting, or bumping into each other – bombs, volcanoes, tectonic plates. The desire to make an impact on the audience by depicting these events can lead to a need for very high signal levels at low frequencies.

Although the bandwidth of the main channels of Dolby Digital can go to 0Hz, the signal level required for extreme impact might be more than can be represented without digital clipping. The specification of the LFE channel requires 10dB of gain to be applied to it on reproduction. Figure 3 shows how the LFE signal can be combined with the main channels and sent to the loudspeakers. The application of the 10dB gain and combination with the main channels must be done in such a way that overload is not caused. It could, for example, be done in the analogue domain.



**Figure 3: Correct use of LFE channel with “big” loudspeakers**

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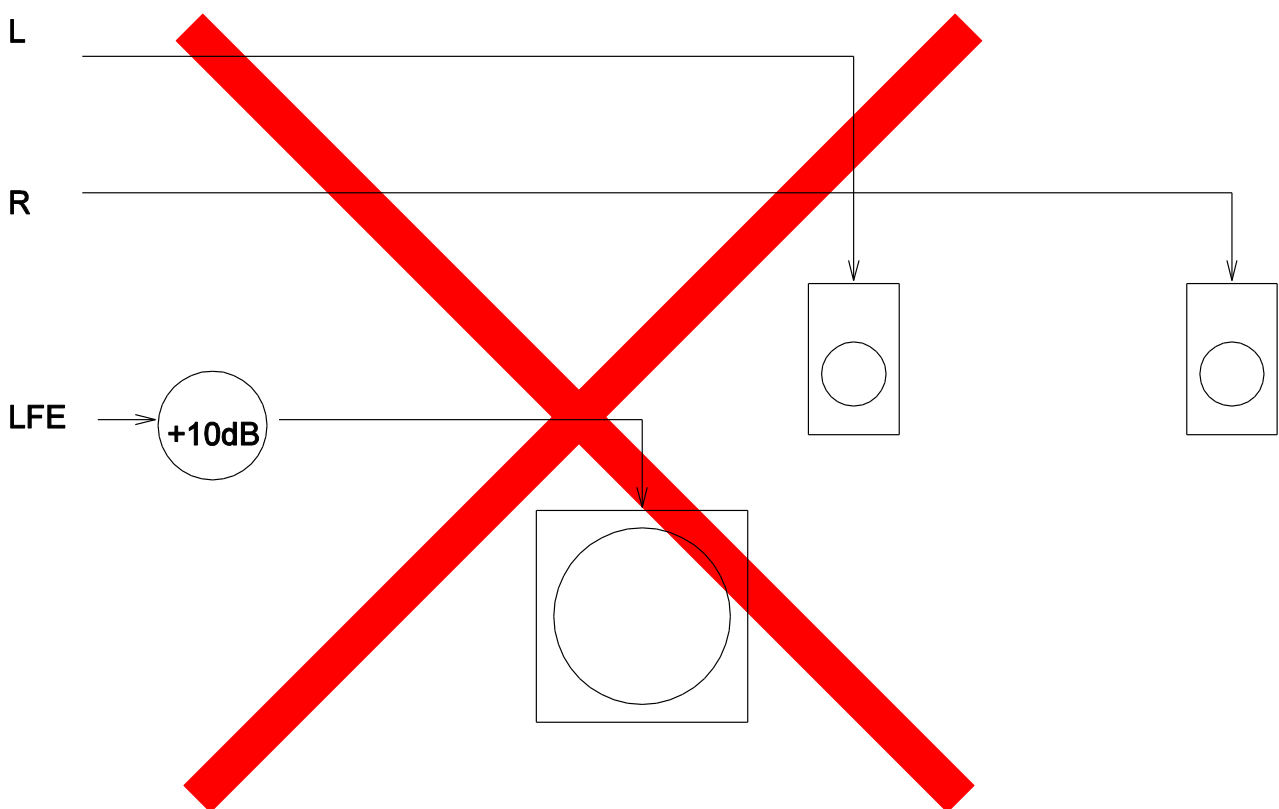
The figure shows two main channels and the LFE channel, but the same principle applies to mono (where the 6dB attenuation would not be required), or to systems with more loudspeakers, (where more than 6dB attenuation would be required if the LFE were added to all loudspeaker signals).

So that's it: the sub-woofer and the LFE explained. When treated separately, they're relatively simple. What could possibly go wrong?

#### 4 Connecting the LFE to the sub-woofer

Figure 4 shows a system where the LFE channel is connected to a sub-woofer in a system with small loudspeakers. This is wrong.

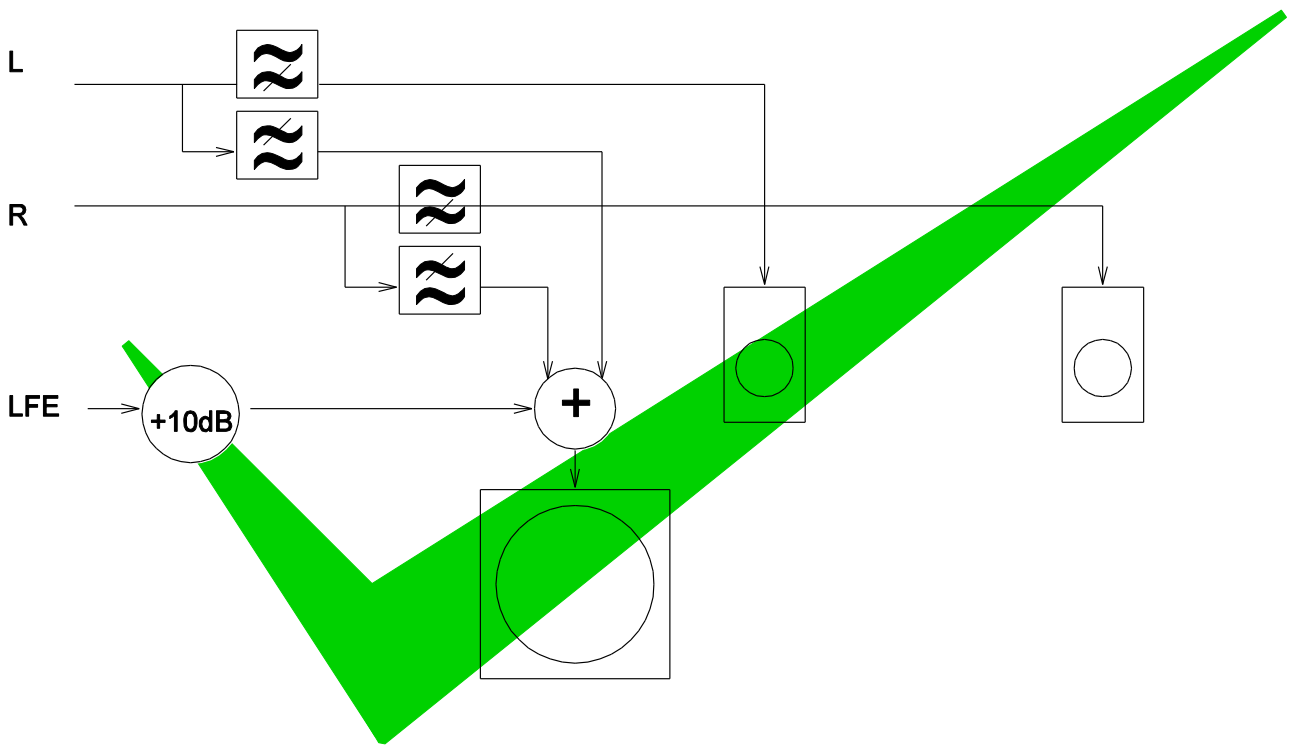
The low frequencies in the main channels are not reproducible by the small loudspeakers, and the sub-woofer only gets effects signals (think “enhancements”) that would otherwise overload the main channels. A significant part of the programme content is lost.



**Figure 4: Incorrect use of LFE with “small” loudspeakers. Bass from main channels is not reproduced**

Considering the two introductory sections earlier, describing separately the LFE channel and use of a sub-woofer, we should be able to configure a system properly. Figure 5 shows a “2.1” system, correctly configured, using bass management. Low frequencies from the main channels, and effects from the LFE channel, are directed to the sub-woofer.

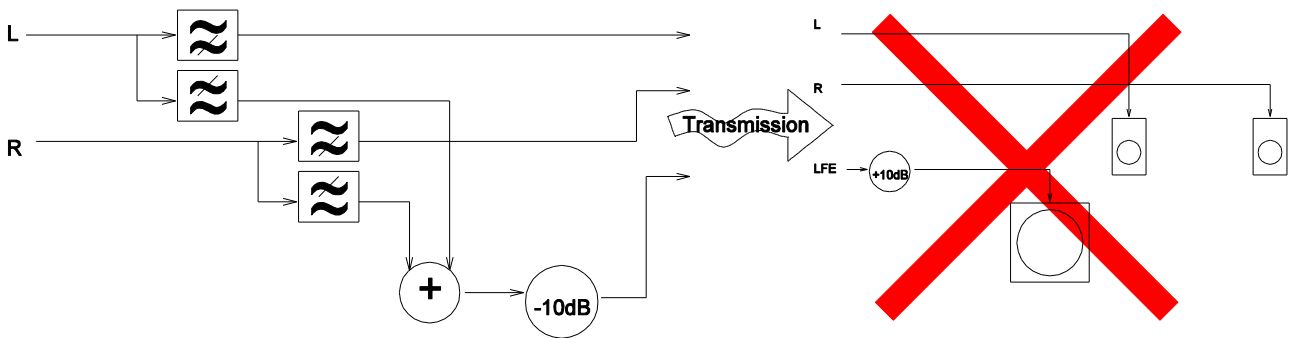




**Figure 5: Correct use of LFE and bass management with “small” loudspeakers**

This looks rather more complex than the simple way of doing it wrong (as in Figure 4).

A broadcaster might be tempted to pre-process its transmissions to take account of incorrect configuration in the home. Although it is commonly taught that “two wrongs do not make a right”, there is a way of trying that with an LFE channel and a sub-woofer. Figure 6 shows signals from the main channels being put into the LFE signal before transmission, on the assumption that they will be reproduced by the sub-woofer in the home.



**Figure 6: Bass “mismanagement” before transmission to compensate for incorrect configuration in the home (only two channels shown)**

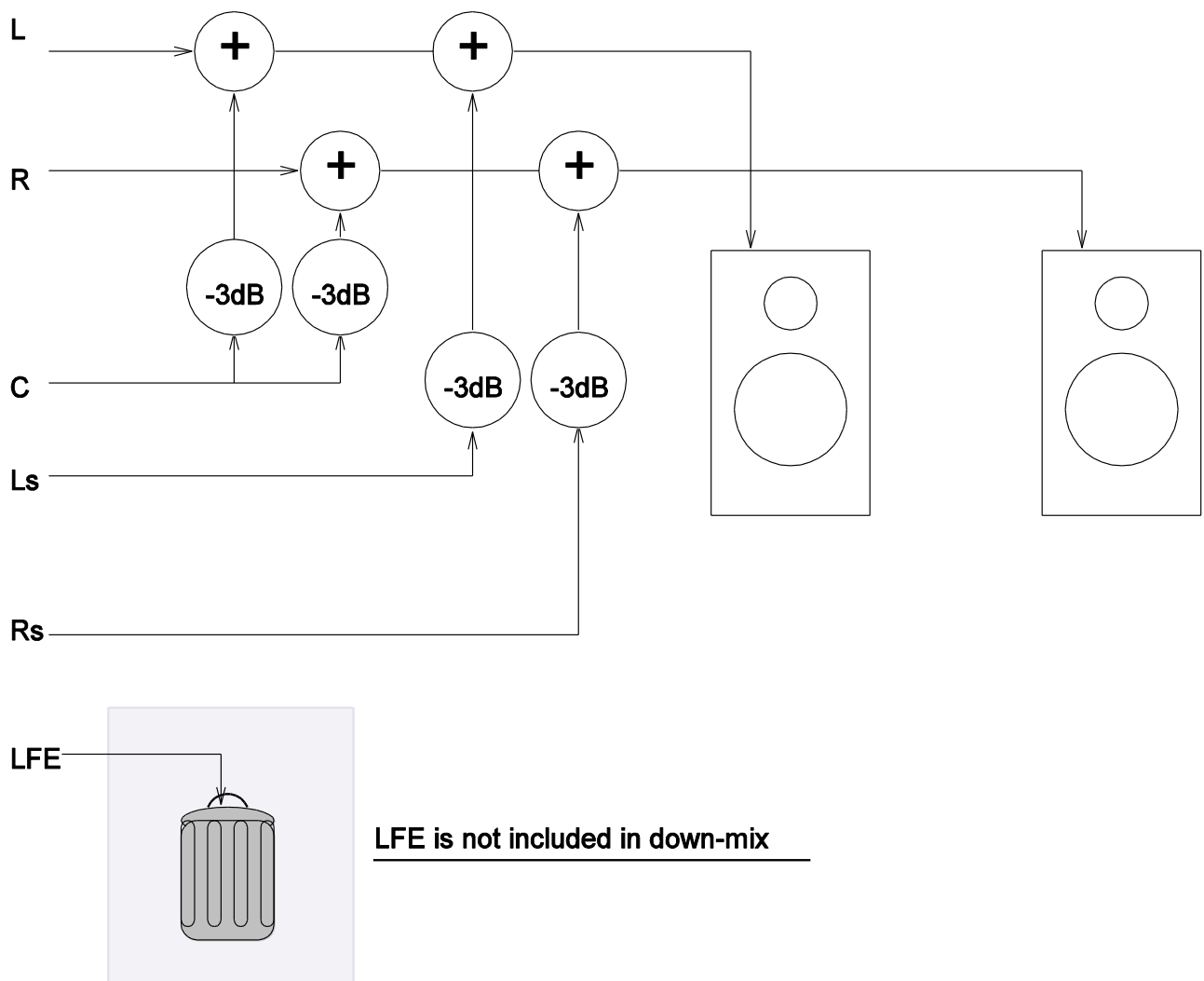
This misuse of bass management, the LFE channel, and sub-woofer is further complicated by the question of frequency responses. Figure 6, although “wrong”, could work for some people, but it depends on correct matching of frequency responses. If the cross-over frequency of the band-splitting filters in transmission do not match the responses of the sub-woofer and main loudspeakers, there will be a hole, either because content that was too low in frequency to be reproduced by the main loudspeakers was not put in the LFE, or content that was put in the LFE was of too high a frequency to be reproduced by it.

No assumptions can be made about the frequency responses of the loudspeakers and subwoofer, since that depends entirely on the designer and manufacturer.

As well as misusing the LFE channel, this does not take into account one of the facts of life in surround sound broadcasting: most of the audience does not listen to surround sound, and this brings us to the subject of “**down-mixing**”.

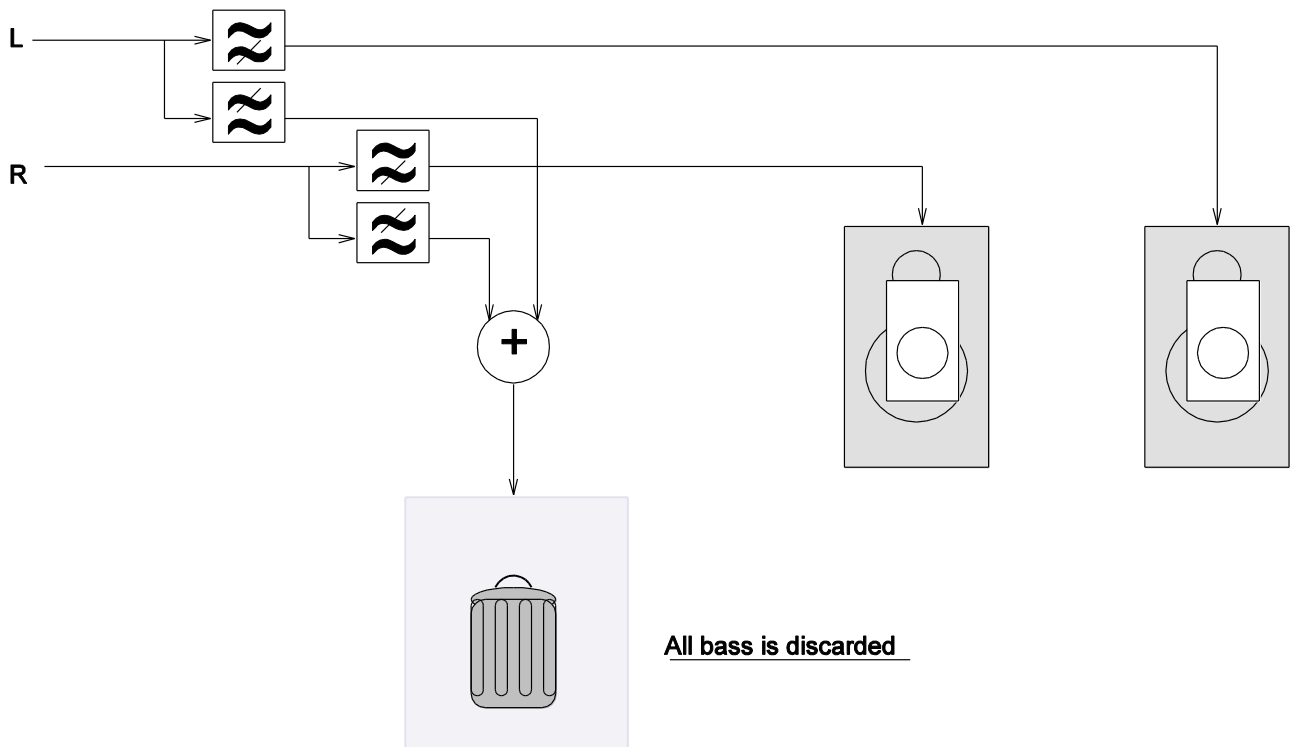
## 5 Down-mix of broadcast surround sound

Even when listening to broadcasts transmitted in surround sound much of the audience continues to use only two loudspeakers, whether for cost reasons, or practicalities of installation. These listeners hear a down-mix, where the centre channel and surround channels are mixed into the front left and front right channels (to an extent controlled by metadata in the broadcast audio stream). Figure 7 shows how this is done in the receiver. The attenuations shown as 3dB are just examples, and the actual values are under the control of the broadcaster, sent as metadata in the audio stream. What is always the same, because this is how the down-mix algorithm is defined, is that the LFE channel is not included in the down-mix.



**Figure 7: Down-mix of "5.1" surround sound to two-channel stereo discards LFE channel**

Bearing this in mind, we can see that the net result of the “two wrongs” shown in Figure 6, will be as shown in Figure 8. The audience with two loudspeakers will get small loudspeaker sound, whether they have small or large loudspeakers.



**Figure 8: Net result of bass miss-management before transmission, for audience of down-mix on “big” loudspeakers, is “small” loudspeakers sound.**

The broadcaster could try to remedy this by adding a third wrong, and, rather than removing the low frequencies from the main channels and putting them in the LFE channel, they could be duplicated, and be present in the main channels as well. That way the audience that had invested in a correctly configured surround sound system with bass management and a sub-woofer would get double what they should.

The LFE channel must therefore be considered as, at most, an enhancement, and definitely not as a normal part of the mix. It has been suggested that the LFE could be seen as an enhancement specifically for the audience that has invested in surround sound, on the assumption that the rest of the audience is likely to be listening to inferior stereo loudspeakers that would be overloaded if large levels of low frequency signals were present in the main channels. The degree to which this is a problem, compared to the level at which signals clip, has not been established, and it must be borne in mind that the audience of the stereo signal must not feel that they are not getting the full programme.

## 6 Dolby E LFE and Dolby AC-3 LFE

There is a more subtle risk during programme production. Broadcast chains that use Dolby Digital often use Dolby E during production, because it allows the surround sound signals to be stored and conveyed using existing stereo equipment and infrastructure. The frequency response of the LFE channel in Dolby E is not the same as that of Dolby Digital. It is possible to put much higher frequency content in the Dolby E LFE channel than will make it through the Dolby Digital coder, making it all the more difficult to be sure that what the audience gets at home is what was intended in the studio. Even with careful configuration and bass management in the studio, a wide-band signal put into a Dolby E LFE channel will be low-pass filtered by the time it reaches the audience.

The transition from using Dolby E to using linear PCM means that the scope for incompatible LFE channel signals to be produced is even greater.

## 7 Conclusions

A sub-woofer is a valuable addition to loudspeaker systems with limited bass response, as long as bass management is properly configured. It should be understood that it is not related in any way to the LFE channel. The sub-woofer is connected to a bass management system, not to the LFE channel. The bass from the main channels may be added to the LFE signal, and the combination then fed to a sub-woofer, or the LFE signal may be added to the main channels and the combination fed to the main loudspeakers. Direct connection of the LFE to the sub-woofer relies on the assumption that the frequency responses (and overall gain) of all loudspeakers, all sub-woofers, and all bass management systems are designed to interoperate. This assumption is clearly incorrect.

The purpose of the low-frequency effects (enhancement) channel is to carry extra-loud (low frequency) signals, beyond the level capabilities of normal channels. It does not extend any lower in frequency response than the main channels. The need for an LFE channel for domestic broadcasting is therefore limited. The LFE channel in a "5.1" system need only be active when all of the main 5 channels reach clipping.

Operational and configuration problems arise from the use of the LFE channel. These are compounded by the use of sub-woofers when there are misunderstandings of the rôle of both. No attempt should be made to compensate for assumed characteristics of incorrectly configured domestic installations by using the LFE channel.

Further complication arises from the wide-spread use of stereo down-mixing in preference to surround sound loudspeaker systems. All content of the LFE channel is simply discarded in this situation. The main channels **must** contain all the programme elements necessary for the audience.

It is recommended therefore that a silent LFE channel be considered the norm for surround sound production for television and radio. If its use is thought advantageous in particular circumstances then it should only be used when there is a full understanding of the way the whole system of LFE, stereo down-mix, bass management, and sub-woofers is intended to work.

## 8 References

- 1) ETSI TS 102 366 : "Digital Audio Compression (AC-3, Enhanced AC-3) Standard", ETSI,
- 2) ISO/IEC 14496-3 : "Information technology -- Coding of audio-visual objects - Part 3: Audio