Lexicon Logic 7 – The Multichannel Solution

The high quality 5.1 channel material currently being produced in quantity by the film industry is demonstrating the advantages of multichannel sound to all consumers. 5.1 channel music material is just starting to be available. Yet would-be customers of multichannel systems often have substantial collections of two channel material, both films and music. Playing stereo music on a multichannel system does not fulfill the purpose of the new system, but potential buyers are reluctant to replace their entire collections with expensive 5.1 channel releases in a format which is incompatible with all the other playback equipment they own. You can not currently play them in your car. Similarly, music producers are reluctant to mix their new releases in a format that so few people can play. How can we get this ball rolling?

Lexicon has been working on matrix systems for many years – primarily for film. As the quality of these systems increased it suddenly became apparent that they could be much more than a stop-gap between Pro-Logic and fully discrete surround. Our Logic 7 matrix system is truly stereo compatible. A five channel recording passed through our Logic 7 encoder retains all the musical balance of the original recording, and plays as a successful stereo recording. More importantly, recordings mixed for stereo reproduction – which includes almost everything released in the past 30 years – can be reproduced in surround through our Logic 7 matrix decoder. The surround playback has the same musical balance as the original, and has greatly increased listening area and envelopment.

This improvement in sound with standard stereo recordings is particularly evident in small playback rooms, such as automobiles. Stereo sound in autos is poorly balanced both in the front and in the back. The walls of the cabin are always obvious, and the sound seems pressed into the center. The rear seat is particularly bad, with sound coming from behind the listener's heads, and a soundstage pressed into the middle. Adding a Logic 7 system to the car dramatically increases the spaciousness of the sound for all the seats. It widens the front image for the driver and the front passenger, giving each of them an ideal soundstage. At the same time the walls of the car disappear, and the sound seems all around you. The rear passengers get an enormous improvement. Suddenly the front image is back in front where it belongs, and the rear speakers disappear. This is the right way to listen to music in cars!

Another real surprise happens when you use the new matrix as a 5-2-5 codec. An encoded and decoded 5.1 channel recording retains the balance and spaciousness of the original, with nearly every effect and instrument in the right place. The matrix version is perceived as equally exciting as the original, and sometimes better spatially balanced. The success of the psychoacoustically based spatial encoding and decoding process is comparable to the success of psychoacoustic data reduction systems such as AC3 and DTS. The matrix works well – and it can be decoded with far less hardware.

Logic 7 offers a powerful solution to the problem of making a truly universal playback system. The Logic 7 matrix needs no adjustment to successfully play all kinds of material in full surround. Stereo recordings, radio broadcasts, television broadcasts, and standard Lt Rt (Dolby Surround) films are all optimally reproduced. In addition, our Logic 7 encoder produces an Lt Rt track that is identical or superior to one made with the standard film encoder.

The Psychoacoustics of localization and envelopment

Logic 7 is based on our research into how we perceive sound events. The process of stream formation is critical. Our hearing process organizes incoming sound first into events – intervals of sound separated by short periods of silence or by changes in pitch. Events are then grouped by continuity of timbre, direction, or meaning into streams of related events – such as a melody played by a single instrument, or syllables spoken by a particular person. We call this type of stream a foreground stream, since it contains linked elements with specific meaning. It is possible to recognize several foreground streams at the same time – for example one can choose to listen to one out of a group of people talking at the same time. The separate identification of different talkers, called the "cocktail party effect", works as long as syllables from the several talkers do not occupy the same set of critical bands at the same time. If by chance two syllables happen to collide, the ability to identify the meaning and the direction of each is lost. Speech is sufficiently redundant that this does not hinder the comprehension of native speakers.

The important point is that we can listen to only one sonic event at a time (unless two or more events occupy quite different frequency bands.) If we design a matrix decoder which is fast enough to switch the direction of sound events from two different sources, we can convince the listener that we have completely separated the various foreground streams. It is seldom necessary to have completely independent channels.

Foreground streams are not the only kind of stream. We can be acutely aware of sounds that fit into the spaces between foreground events. For example, as a person talks a listener can often easily hear the sound of the room – even when the room is small and not reverberant. The sounds between foreground events form another type of stream – the background stream. Unlike foreground streams, there can be only one background stream, and when the stream is pitched, it can have only one pitch. We are aware when the background comes primarily from the front, or from the side. Like the foreground stream, the background stream can have a direction. Most importantly, when the sound makes up the background comes from all directions, we can perceive envelopment.

Envelopment is the Holy Grail of concert hall design. As long as the background does not intrude on the clarity of the foreground stream(s), people want as much as possible. The perception of envelopment depends primarily on the loudness and the spatial properties of sound that fits between the gaps in foreground sound streams. In general the greater the loudness and the spatial diffusion of the reverberation, the higher the

envelopment. High spatial diffusion depends on having sufficient laterally moving sound, sound that moves across the width of the room.

It is in the reproduction of envelopment that four channel matrix systems fail. If you have a pair of loudspeakers at the sides or to the rear of a listener, and you drive these speakers in parallel with a mono signal, no laterally moving sound is produced. Instead of feeling surrounded by the sound, the listener perceives the sound as coming from the front, or from inside the head. To produce sound that can be enveloping, the drive to the side speakers must be different – ideally preserving the left/right differences in the original recording.

There is another type of envelopment, one that does not depend on separating a sound stream into foreground and background. For example, a chorus recorded in stereo sounds wide and often enveloping when reproduced in stereo. There are several psychoacoustic reasons for this width, but all of them depend on maintaining the left-right separation of the original signal. For example, if we add a center speaker by summing the two input signals and sending them to the center, the added signal power in the middle reduces the separation of the left and right channels. The result is low spaciousness and envelopment. The producer of a 5 channel recording might want to mix a stereo recoding of a chorus into the two rear channels. When this recording is encoded, our decoder must be able to reproduce the encoded signal primarily through the rear speakers, and to maintain full left-right separation at all times.

The psychoacoustics of musical balance

Matrix system work by actively assigning the incoming two channel sound into output channels which represent different directions around the listener. It was not initially clear how this directional process affects the musical balance. We found through experiments that in typical listening rooms it is the total sound power in the listening room which matters. In other words, the balance in the stereo recording will be preserved in the listening room if the different components have the same power ratios in the room that they have in the original recording.

This means that in designing our matrix system we must be very careful to be sure the vocals and the dialog, maintain the same power in the decoder outputs that they had in the recording.

Logic 7 solutions

In light of these principles, our goal was to accurately reproduce the direction of foreground sound events, while preserving the maximum left/right differences of the background sound. We must do this while maintaining the power balance of the original signals.

Directional encoding and decoding

Standard film encoding and decoding uses four main directions, encoded through amplitude and phase. To maintain compatibility with standard encoding Logic 7 retains these four directions. In a five channel version of Logic 7 the surround direction is decoded by making both rear outputs equal and in phase, with no signal from any of the front three outputs.

Left Front output => Left in only
Right Front output => Right in only
Center output => Left in = Right in
Surround (rear) output => Left in = - Right in

Logic 7 adds two additional directions.

Left Rear output => Right in = -.42 * Left in
Right Rear output => Left in = -.42 * Right in

A left rear output is encoded when the right input is out of phase with respect to the left input, but attenuated by 0.42. The right rear output is similar. If we assume the left and right inputs are related by a sine/cosine pan, then the left rear output is exactly half way between left and surround.

The Logic 7 decoder is designed to detect these six directions and to pan sounds smoothly between them. When sound is directed fully in one of the 5 directions that correspond to a single output, the other outputs of the decoder are reduced by at least 20dB.

The rear directional decoding used by Logic 7 gives considerable separation between the left and right rear channels when playing a standard Lt Rt film. This is because all pans between the left input and the surround input of a standard film encoder will decode with Logic 7 as a smooth pan first from left to left surround, and then to full rear.

The Logic 7 encoder includes active circuitry to ensure that the correct phase and amplitude is created regardless of how the signals are panned. One can pan a signal from any front input to any rear input and have a directionally sensible result. Panning between the two rear inputs will result in smooth movement between the two rear outputs of the decoder – and constant energy in the room.

In phase signals applied to the rear inputs of the encoder will result in an Lt Rt signal which is equal and out of phase – exactly like the standard film encoder. Out of phase signals applied to the rear inputs of the encoder result in neutral steering in the decoder. Decorrelated signals applied to the rear inputs will result in just enough antiphase signal to have the decoder move the stereo sound field to the rear loudspeakers.

Constant energy in encode and decode

The encoder uses active circuitry to maintain constant energy in its outputs. That is, a signal applied to any input appears with the same total power on the outputs of the encoder. This is not true of signals applied to the Dolby film encoder, or the European standard IEC encoder. In these encoders there is a 3dB attenuation of a signal applied to a rear input. In other words, a sound effect applied to the left rear input of the standard encoder will be 3dB too soft in stereo, in Pro-Logic, and in a Logic 7 decoder. Signals that are equal and in phase in the rear inputs of a standard film encoder will play with the correct loudness and direction through a Logic 7 and a Pro-Logic decoder. The same signals applied to an IEC standard encoder will play with the correct loudness, but will decode to the front rather than to the rear.

Decorrelated signals applied to the rear inputs of the IEC encoder and the standard encoder also are attenuated by 3dB. For the Dolby film encoder this is an unavoidable artifact of maintaining the correct level when the rear inputs are in phase. In the IEC encoder this 3dB attenuation was carefully chosen after a series of listening tests with classical music, where the rear channels were primarily reverberation. These tests were performed by the German broadcast institute, the IRT.

The tests of the IEC encoder by the IRT found that without the 3dB attenuation the stereo output (Lt Rt) of the encoder is overly reverberant. To produce the best stereo compatibility of the Lt Rt signals, the 3dB attenuation was chosen. The Logic 7 encoder uses active circuitry to recognize when the rear channels are mostly reverberation, and introduces the 3dB attenuation in this case. Thus the Logic 7 encoder maintains compatibility with the IEC standard.

The Logic 7 decoder also has been designed to keep energy in the room the same as the energy ratios between different components of the input signal. This is particularly obvious with a stereo recording. Pro-Logic does not reproduce the energy balance correctly for the center channel. If you compare a Pro-Logic and a stereo playback of a popular music CD, you will hear that the vocals are more difficult to hear in the Pro-Logic playback. If you do the same comparison with Logic 7 you will find the balance identical when you switch back to stereo.

Full separation of the rear channels during background and rear stereo

It is essential for creating envelopment that the rear channels should be fully decorrelated during the background sounds. Logic 7 achieves this by making the left rear channel identical (except for delay and frequency balance) to the left input channel whenever the inputs to the decoder are decorrelated. The switch between directional steering and the background steering is rapid enough that the ear hears the background as continuous, and as wide as natural hearing. Delay, level and frequency balance of the rear channels are adjusted to make a natural and inaudible transition between a slightly forward sound, such as an orchestra, and a fully surrounding sound, such as reverberation. (The decoder includes a circuit that detects a surround recording, and readjusts the rear channels for full bandwidth.)

In addition the Logic 7 decoder includes circuitry to reproduce a forward or rearward panned stereo signal with full separation. The result can be extremely effective when used tastefully in a mix. It also allows antiphonal pieces to be reproduced exactly as they were recorded.

Full width of the front sound stage

A major problem with stereo recordings played over a Pro-Logic decoder is the reduction in the width of the front image. When the inputs to the decoder are uncorrelated – such as during stereo classical music – the center channel has the same loudness as the left and the right channels. All three loudspeakers produce equal power in the room.

This is a minimum power for the center channel in the Pro-Logic circuit during neutral or forward steering. As the forward bias increases, such as during vocals in a popular music piece, the power in the center channel increases 3dB. The power in the left and right front channels decreases about the same amount.

Even with decorrelated inputs Pro-Logic results is an easily noticeable reduction in stereo width and spaciousness. For a popular recording with a substantial forward bias, the reduction in width is even greater.

We studied this problem in detail in the design of Logic 7. In the current version the loudness of the center channel is very carefully controlled. For uncorrelated inputs the center channel power is reduced 4.5dB relative to the left and right speakers. Although this results in a slight reduction in the spaciousness when you listen to only the front loudspeakers, the loss is more than compensated by the fully independent rear speakers. As the balance moves forward the center channel level increases, reaching equal power at the forward bias of a typical popular recording. However, since the increase is dynamic, the speaker reverts to low level during the gaps between sound events, and full envelopment is preserved.

Not just envelopment is preserved. Many recordings contain very interesting sounds at low levels which dance around the front image during and surrounding the vocals. Logic 7 preserves the left/right separation of these low level sounds. The improvement over Pro-Logic is dramatic.

Conclusion

Logic 7 offers a universal multichannel sound solution. It plays normal stereo recordings with a wide sound stage and increased envelopment, while standing ready to play encoded material in full surround. The improvement in listening area and envelopment are particularly noticeable in small spaces, such as in automobiles. Logic 7 also provides a technology for recording and distributing multichannel sound on two channel media. It uses psychoacoustic techniques to reproduce the full benefits of the original multichannel

recording, while allowing compatible stereo playback and broadcast. Logic 7 encoders and decoders are available now from Lexicon, and integrated Logic 7 decoder chips are also available from at least one major manufacturer.