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REPORT*

NATIONAL RADIO SYSTEMS COMMITTEE

**NRSC-R207
Broadcasting Surround Sound
Audio Over IBOC Digital Radio –
Issues and Resources for FM
Broadcasters
January 10, 2007**



NAB: 1771 N Street, N.W.
Washington, DC 20036
Tel: (202) 429-5356 Fax: (202) 775-4981



CEA: 1919 South Eads Street
Arlington, VA 22202
Tel: (703) 907-7660 Fax: (703) 907-8113

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NRSC-R207

FOREWORD

NRSC-R207, Broadcasting Surround Sound Audio Over IBOC Digital Radio – Issues and Resources for FM Broadcasters, is intended as an aid to FM radio broadcasters as they consider how to enhance their in-band/on-channel (IBOC) digital radio broadcast services beyond 2-channel stereo audio to accommodate multichannel (or surround sound) capability. The DAB Subcommittee co-chairmen at the time of adoption of NRSC-R207 were Mike Bergman and Milford Smith; the NRSC chairman at the time of adoption was Charles Morgan.

The NRSC is jointly sponsored by the Consumer Electronics Association and the National Association of Broadcasters. It serves as an industry-wide standards-setting body for technical aspects of terrestrial over-the-air radio broadcasting systems in the United States.

Broadcasting Surround Sound Audio over IBOC Digital Radio – Issues and Resources for FM Broadcasters

Table of Contents

1	Background.....	5
	<i>Multichannel sound</i>	5
	<i>Defining terms</i>	7
	<i>Applying multichannel systems to IBOC</i>	8
	<i>iBiquity involvement in surround sound</i>	9
	<i>Single-ended/receiver upmix surround options</i>	9
	Situation 1 – Broadcaster uses no surround encoding:	9
	Situation 2 – Broadcaster uses composite or component surround encoding:.....	10
2	System implementation	13
	<i>Fundamental decisions</i>	13
	<i>Initial implementation</i>	14
	<i>Producing local content in surround</i>	15
	<i>Component and/or combination systems</i>	17
	<i>Content availability and issues</i>	19
	5.1/2.0 compatibility of content.....	19
	Downmixing options	20
	Monitoring.....	20
	Downmixing algorithms and techniques	21
	Synchronization.....	22
3	Compatibility between surround systems.....	24
4	Surround sound and multicasting	26
5	Impact on the analog signal	27
	<i>Background</i>	27
	<i>Composite surround methods and multipath</i>	28
	<i>NPR Labs study on impact of composite surround signals on stereo analog FM</i>	28
6	Testing surround system on your station.....	30
7	Additional resources	31
	Annex 1 – Dolby ProLogic II	
	Annex 2 – The MPEG Surround Codec	
	Annex 3 – Neural Surround	
	Annex 4 – SRS Circle Surround	
	Annex 5 – An overview of the causes of distortion in FM signal reception	

1 **Background**

This document is intended as an aid to FM radio broadcasters as they consider how to enhance their in-band/on-channel (IBOC) digital radio broadcast services beyond 2-channel stereo audio to accommodate multichannel (or *surround sound*) capability. It is not intended to be prescriptive, or to make specific recommendations, but as a guide to the numerous issues that broadcast facilities will encounter in such a transition.

This document has been created by the NRSC's Surround Sound Audio Task Group (SSATG), which was established to "...assess how to best handle compatible surround sound technologies on an industry-wide basis and provide a recommendation to the DAB [now DRB] Subcommittee on this."¹ The SSATG is fortunate to count among its membership some of the world's foremost experts on this subject, and in the course of its work, the group has explored a wide range of issues. This document represents a report of the SSATG to the U.S. radio industry on the current status of, and options for, surround sound on FM IBOC radio, and offers guidance for broadcasters on how to proceed.

Multichannel sound

It is well known that there are audio formats with spatial characteristics that extend beyond stereo, and that these formats have become quite popular in media other than radio broadcasting. The conversion to IBOC digital radio broadcasting is therefore a timely opportunity for broadcasters to consider the inclusion of this capability in emerging radio services.

This technology is collectively referred to as multichannel audio, although the generic term surround sound is often used to describe anything with more than two reproduction channels. Most recent progress in this area has taken place in the cinematic and television sound industries, but a growing body of work in pure-audio applications now exists, primarily in the form of commercial music releases, concert recordings and radio drama productions.

With a few exceptions, this content is produced today in a five-channel form, with a configuration intended for reproduction with speakers' placement relative to the primary listening position as left-front (LF), center-front (CF), right-front (RF), left-back (LB) and right-back (RB). Despite this placement description, however, it is conventional to refer to the two back channels in this configuration as *left surround* (LS) and *right surround* (RS), while the center-front channel is typically called simply *center* (C). A narrowband sixth channel is sometimes added for low frequency effects (LFE), with its content fed to a subwoofer that can be placed anywhere in the listening area.

Given that the LFE channel's bandwidth is about 1/10th that of the other five full-range channels, this format has come to be known as *5.1 channel surround*. It is the standard format for most multichannel music content produced today. See Figure 1.

¹ See NRSC Full Committee, Minutes of the January 7, 2005 Meeting.

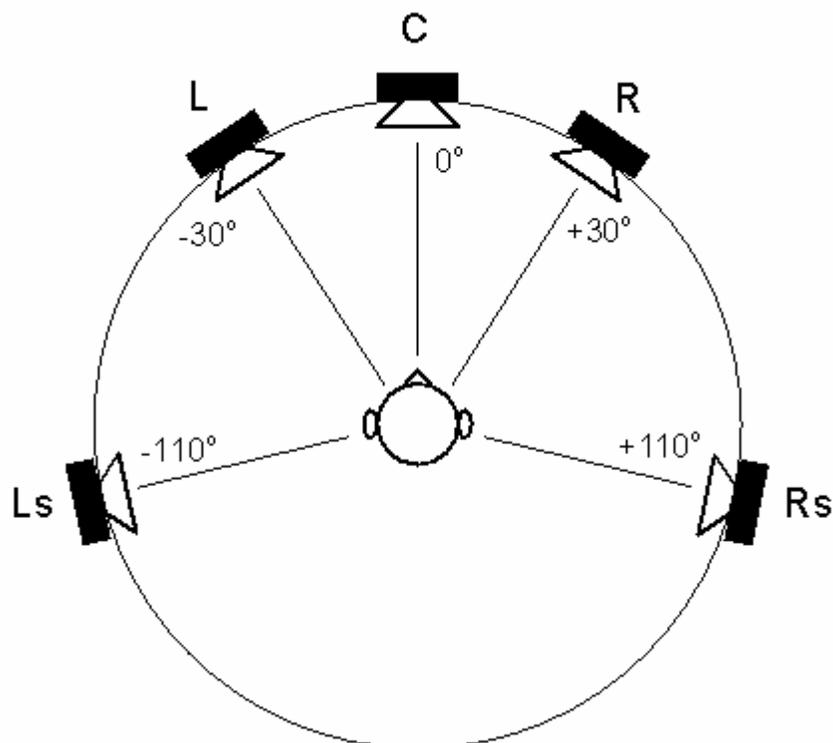


Figure 1. Recommended placement of the five main-channel speakers in a 5.1 surround monitoring environment.² Subwoofer for LFE channel, if used, can be placed anywhere in the room, typically in a corner for maximum LF coupling.

The additional channels of a surround format would nearly triple the bandwidth and storage requirements of a given audio selection over its stereo (two-channel) representation. Therefore numerous encoding systems have been devised to reduce the extended bandwidth requirements of surround sound, for more efficient use of storage and transmission resources. Such systems are particularly useful (if not essential) for application of surround-sound to transmission within the scarce spectrum of broadcasting.³

Some of these systems are purposely designed to retrofit surround content into existing stereo infrastructures to simplify facility transition, and to allow stereo and surround audio to easily coexist within a facility. Others approaches do not make such accommodations. These divergent approaches are described in some detail in Annexes 1-4,⁴ but meanwhile the reader is cautioned that the very existence of multiple systems—some of which are already in wide use outside of the radio broadcasting sphere, and some of which show promise but currently remain in development—complicates the transition for IBOC surround.

² See ITU-R Recommendation BS.775-1, *Multichannel Stereophonic Sound System with and without Accompanying Picture* (listed in Additional resources section below) for additional information.

³ Transmission of surround sound signals is only considered practical over FM IBOC; the limited capacity of AM IBOC (36 kbps for hybrid mode) is not considered sufficient for multichannel audio broadcasting.

⁴ These annexes are not a work product of the NRSC but rather are included for informational purposes only.

Defining terms

Given such complexity, the SSATG found it helpful to define three general terms to describe the different forms in which multichannel audio may appear:

- *Discrete multichannel audio* – the *production format* (and typically, the release format) of multichannel content, in which all five (or more) channels are kept wholly separate from one another, and all signals are fed to and from audio devices via isolated audio paths.
- *Composite surround format* – a system that converges a discrete multichannel audio signal into a smaller number of channels (no less than two), via an encode/decode approach that allows downstream re-extraction of a multichannel signal. (This approach allows the storage and transport of surround audio on existing stereo architectures, either analog or digital.)
- *Component surround format* – a digital-only approach wherein audio data and multichannel *spatial bitstream* data are maintained as separate signals. Downstream processing can apply the spatial data to the audio data to re-extract a multichannel signal. (This approach allows the audio data to be managed independently from its spatial reproduction format.)

An important term of art in this context is *downmixing*, the name applied to the process by which a multichannel audio signal is reduced to a fewer number of channels, typically 5.1 to 2.0 (i.e., stereo) or 1.0 (i.e., mono). It is the conceptual equivalent of summing a stereo signal to mono, but of course with greater variability given the number of channels and their differing content. Downmixing of multichannel signals can be done manually by an operator, or automatically by a mixing device. Certain standard downmixing algorithms have been developed for application to the latter process.⁵

Another useful concept encountered by the SSATG was the consideration of so-called *pseudo-surround*, which refers to the artificial and essentially automatic creation of a multichannel audio signal from a stereo audio source. There are two popular forms of pseudo-surround. One is *surround creation*, the other is *surround extraction*. Creation includes processes such as room simulation, reverb, echoes, and the like, adding signals that were never in the source. Extraction only redistributes sounds from the original stereo program. No new sounds are added.

Pseudo-surround is not a new concept, having originated in the 1970s, but it is important to distinguish it from a surround mix that was purposely created via discrete multichannel production. A term of art often applied to artificial surround creation is *upmixing*, whereby a multichannel signal is created from a source signal of fewer channels (typically generating a 5.1-channel output from a 2.0-channel source). Importantly, this technique can be applied either at the transmit- or the receive-end of a broadcast service.

Occasionally, the term *single-ended surround* is applied to the upmixing approach; a further variant in nomenclature is *blind upmixing*, which refers to the fact that the process is being controlled by a device's preset programming, not in response to any instructions from the content or a live operator.

⁵See ITU-R BS.775-1 (listed in Additional resources section below) for additional information.

Given that (at least in the near term) not all content will be available in discrete surround form, there may be times when broadcasters may consider upmixing to enhance non-surround material for broadcast. It turns out that this is not necessary (and may be potentially undesirable), since surround *decoders* have the ability to do this upmixing at the receiver. An exception to this would be if a broadcaster is transmitting a component surround signal and was interested in exercising some amount of control over the blind upmixing process. In this case, the precise (blind) upconversion desired by the broadcaster could be captured in the component signal's side channel, then reproduced by the component surround receiver.

Yet another useful term is *artistic stereo*, which refers to an original stereo music mix as produced by an artist and released as a stereo product. This distinguishes that mix from a stereo signal that is derived by downmixing (either manually or automatically) a multichannel release of the same content. The term arises from the fact that in the latter case, the artist has no control over how the downmix may actually be performed, and how the resulting stereo product may sound. (More on this point below, under *Content Availability and Issues*.)

Finally, some other helpful nomenclature in common use by the audio industry today identifies the various audio channels in a multichannel context with commonly accepted terms. A true, original (or "plain") stereo signal is labeled *Lo/Ro* (or *L_o/R_o*, the "O" standing for "only"), while a two-channel signal carrying composite surround encoding is labeled *Lt/Rt* (or *L_T/R_T*, the "T" standing for "total"). Meanwhile, the six channels of 5.1-channel surround are abbreviated as L, C, R, LS, RS and LFE. Note also that when the six channels are transported over paired two-channel paths (such as AES3), they are typically grouped as L/R, C/LFE and LS/RS, although some variation in this may be encountered.

Applying multichannel systems to IBOC

It is fairly elementary to apply a composite surround system to IBOC, given that these systems all output a 2.0-channel audio signal. Three such systems, described in Annexes 1, 3, and 4, have been proposed for such application, and all have been evaluated by iBiquity Digital for use with HDC encoding in HD Radio™ implementations of FM IBOC broadcasting.⁶ In each case, iBiquity Digital has concluded the surround sound information will not have a harmful impact on the HD Radio signal in terms of obvious artifacts or impairments.

Note that for use on an FM IBOC Main Program Service (MPS) audio channel, a composite surround system would likely also be applied to the analog FM signal. See Section 5 below for additional information on this point.

A component surround system would be applied only to the digital audio signal, with its spatial bitstream data signal transmitted as AAS data in the IBOC system. No component surround system has yet reached maturity sufficient for evaluation by iBiquity Digital in HD Radio implementations, but this is expected to occur soon for the MPEG Surround component surround format, described in Annex 2.⁷ If iBiquity Digital determines the MPEG Surround format does not have a harmful impact on the HD Radio signal, it is likely that a standard method of carriage for the MPEG Surround spatial bitstream data in the Advanced Application Services (AAS) transport portion of the HD Radio signal will also be specified.

⁶ HD Radio is a trademark of iBiquity Digital Corporation.

⁷ A number of successful demonstrations of prototype MPEG Surround signals over HD Radio transmissions have been conducted including a demonstration in January 2006 in Boston and at two booths at the 2006 NAB Convention. These demonstrations used a full broadcast signal chain, with prototype receivers picking up the attenuated output from a HD Radio exciter.

iBiquity involvement in surround sound

As noted above, iBiquity Digital has evaluated several systems to determine whether the surround sound information would have a harmful impact on the quality of the HD Radio signal. iBiquity has not conducted any qualitative evaluation of the surround sound aspects of those systems. In each case, audio recordings of the HD Radio broadcast were made with and without surround sound information. The audio recordings were subjectively evaluated to determine whether the introduction of the surround sound information created noticeable artifacts or other impairments in the HD Radio signal as normally received (i.e. not processed through a surround decoder). For each of the three systems submitted to iBiquity for evaluation, it was determined the surround sound information would not have a harmful impact on the HD Radio system.

iBiquity also has implemented a Surround Sound Identifier in the HD Radio system. Each existing surround sound system was randomly assigned an identifier. Additional systems that are developed in the future will be assigned an identifier. Systems interested in receiving an identifier can contact iBiquity Digital. The current list of identifiers is reproduced below as Table 1.

Table 1. Surround sound system identifiers in the HD Radio system⁸

Value	Surround Sound System
0	None
1	SRS Circle Surround
2	Dolby ProLogic2 Surround
3	Neural Surround
4	FHG MPEG Surround
5	DTS Matrix Surround
6	CT Surround
7-31	Reserved

Single-ended/receiver upmix surround options

Many receivers already in the marketplace are equipped with composite surround sound decoders. This section addresses the various situations that broadcasters and listeners may encounter as surround sound is introduced to digital radio broadcasting.

Situation 1 – Broadcaster uses no surround encoding:

A broadcaster has no surround encoding capability. The only types of signals that can be broadcast are stereo (Lo/Ro) and mono. The following will occur in each of these different receiving/listening conditions:

- a) *Listener has a receiver with a surround decoder:* The only way any surround effects can be generated is if the listener plays stereo content through the surround decoder, which produces an upmixed output. This is a common situation at present, as there are millions

⁸ Note that these values are specific to the iBiquity HD Radio implementation of IBOC and are not part of the NRSC-5-A Standard.

of these decoders currently in the field, and they are often used to listen to unencoded stereo content. In such cases, most decoders will produce a “pleasant” pseudo-surround experience. (This is the condition referred to above as pseudo-surround “extraction.” More on the mechanics of this under Situation 2a below.) If the listener receives a mono signal, the result will be an unchanged mono signal, typically reproduced only in the Center channel output of the decoder.

- b) *Listener has a surround system set to add signal-processing effects, like “party” or “concert hall”*: Also a fairly common situation currently, this is the condition referred to above as pseudo-surround “creation.” With either a Lo/Ro or mono signal, the processor does what it does, and the listener will elect to use it or not.
- c) *Listener has no surround reception capability*: This is the normal mode of listening today. The listener will receive the unchanged Lo/Ro or mono signal.

Situation 2 – Broadcaster uses composite or component surround encoding:

A broadcaster selects a specific surround encoding format. This enables the broadcast of i) multichannel audio encoded into a two-channel signal (Lt/Rt), or ii) a regular stereo signal (Lo/Ro), or iii) a mono signal. The following will occur in each of these different receiving/listening conditions:

- a) *Listener has a receiver with a surround decoder*: If the broadcaster provides a signal encoded in the same format as the listener’s decoder, and reception conditions are adequate, the listener should experience the same surround effects as the broadcaster does in the station’s surround monitoring system. If the listener uses a different decoder format than the broadcaster, it is likely that a surround-sound experience will also be heard by the listener, but it may be somewhat different than what the broadcaster hears. (More detail on such “cross-compatibility” issues between mismatched surround sound encoders and decoders is available below in Section 3.) For this reason, the broadcasters may want to test (or continuously monitor) how different surround decoders react to the station’s surround-encoded signal.

If the broadcaster should feed a Lo/Ro signal (from the legacy stereo library, for instance) to the surround encoder, and the encoder is not set to add any purposeful upmixing (i.e., pseudo-surround creation) effects, the stereo signal will pass through essentially unchanged. But for listeners using a composite surround decoder, these unencoded stereo programs will experience the same pseudo-surround extraction effects noted in Situation 1a above, and these will vary from case to case. To better understand these effects, a basic understanding of how composite decoders look at stereo signals is helpful, along with a brief discussion of the differences between some styles of stereo mixing techniques, as follows.

Composite decoders use relative level and phase differences between the incoming Lt and Rt channels to reconstruct the multichannel version of the program. Component decoders

may also offer a “non-guided” decoding mode⁹ (primarily used in case the side-chain spatial data signal is not available), which similarly looks at channel-level differences and inter-channel cross correlation.¹⁰ In this case, component decoders would produce similar pseudo-surround extraction effects on an unencoded stereo signal.

Most broadcast engineers are aware that some stereo recordings possess more out-of-phase information (i.e., relatively high L-R content) than others. For example, a classical or other acoustic-music stereo recording made with two widely spaced omnidirectional microphones will generally exhibit a higher L-R level than a recording where the stereo image is created with many panned mono microphones that are each positioned close to individual instruments¹¹. When listening in stereo, the panned mono technique leads to a flat stereo image that is confined to the line between the left and right speakers, while the spaced-omni recording tends to produce an image that extends outside the speakers.

When a surround decoder encounters such a panned mono Lo/Ro signal, it cannot find much out-of-phase information in these signals, so it produces a multichannel output that is very similar to the original stereo mix, mostly routed to the Left and Right output channels (perhaps adding a some L+R output to the Center channel, and little L-R output from the surround channels), so the resulting upmix is quite faithful to the original stereo presentation.

On the other hand, the copious amount of L-R information in the spaced-omni Lo/Ro signal will be interpreted by the composite decoder as spatial information, and routed into its multichannel output in a manner that creates a very spacious effect – even though there was no intentional composite surround encoding added to the stereo signal.

Various mixing techniques and signal processors used in studio stereo recordings made with panned mono microphones can also produce these “accidental” surround effects when heard through composite surround decoders. As noted in Situation 1 above, all of these spacious sounding stereo mixes can generally provide a pleasing composite surround presentation, assuming the decoder’s upmixing characteristics are suited to the material. Broadcasters may wish to audition all surround systems of interest, using a wide variety of Lo/Ro content, to better understand how they behave in such cases.

If the broadcaster feeds a mono signal to any surround encoder, it will again pass through unchanged, and will appear to the listener as a Center channel mono signal.

- b) *Listener has a surround system set to add signal-processing effects, like “party” or “concert hall”*: With either a Lt/Rt, a Lo/Ro or a mono signal, the processor will add a variety of pseudo-surround creation effects, and the listener can choose to engage them or not.

⁹ See Breebaart, J., et al., *MPEG Spatial Audio Coding/MPEG Surround: Overview and Current Status* (listed in Additional resources section below) for additional information.

¹⁰ *ibid.*

¹¹ The panned mono technique leads to a relatively tight lower-left-to-upper-right ellipse on an X-Y display, whereas the spaced omni signal tends to produce a broader, oval-shaped or circular display.

- c) *Listener has no surround reception capability*: Although Lt/Rt signals will be interpreted in this case as compatible stereo, some Lt/Rt signals may sound somewhat more spacious when listened to in stereo than others. Thus a composite surround encoder can sometimes provide a more interesting two-channel listening experience than can a “plain old stereo” source. The stereo and mono source signals are unchanged by the composite encoder, so provide exactly the same listening experience as situation 1c.

It is important to note, however, that the Lt/Rt signal heard by the stereo listener in this case will be a stereo downmix of the surround content, which may differ aesthetically from the artistic stereo mix. (For more on this issue, see *Content Availability and Issues* below.) For broadcasters producing their own surround content, the quality of the content’s Lt/Rt downmix and mono sum should be frequently monitored to avoid similar issues. (See also *Producing Local Content in Surround* below.)

2 System implementation

When making the decision to implement surround sound at a radio station, broadcasters need to understand just what might be involved in the conversion. While up-front it may seem like all that is needed is the surround material itself, there may be other hidden expenses involved, depending on the current design of a station's facilities. This section will help in evaluating a current studio layout, and help in determining what changes may need to be made to offer the best surround experience to a station's listeners.

Fundamental decisions

The first step is to decide which method of surround broadcast encoding to use. The various methods are described briefly in previous sections of this report, and in greater detail in Annexes 1-4. The four systems discussed all fall into one of two categories, either composite or component. In general, the composite methods can require fewer changes in a station's facilities and be less expensive to implement, but may come with a tradeoff in the accuracy of the surround reproduction (when compared to the 5.1-channel discrete source material). Component systems, by comparison, will require more upgrades to the studio up-front, but may provide a more accurate reproduction of the original surround material – although with the possible tradeoff in consistency of surround effect when blending to analog. Broadcasters are encouraged to conduct their own listening tests of all of the available systems on the market to help decide how important these tradeoffs may be. Listening studies conducted on both component and composite surround sound systems have shown that listeners rate both types of systems very highly.¹²

Second, a decision needs to be made as to how deeply surround sound is to be incorporated into a station's programming. For example, a decision to broadcast only music programming in surround could be made, but this would result in a station's liners, sweepers, promos, and commercials all missing out on the advantages offered by surround presentation. With the right creative talent, surround production elements have the potential to “jump out of the radio” and make the difference between someone staying with a station through commercial breaks, or tuning to the competition.

Decisions on these options will determine how much cost and effort is involved in converting a radio station to a surround sound environment. Considered in the following paragraphs are various aspects of surround sound conversion, from the easiest to the most involved methods. Areas in a facility that may require modifications or upgrades include:

- Production room equipment
- Control room equipment
- Monitoring systems
- Computer automation/storage
- Expansion of routing switcher capacity
- Studio to transmitter links (STLs)

¹² See Breebaart, J., et.al. (listed in Additional resources section below).

While this list may appear intimidating, it is important to remember that broadcasters can choose how many or how few changes they are willing and/or are able to make and still offer the technology. A broadcaster can also start out with the basics, then improve the facility over time.

Initial implementation

If the most important factor for a station is promoting the fact that it is now broadcasting in surround sound, and a station needs to get surround on the air as quickly and inexpensively as possible, a good option to consider is starting with a music-only content choice, and encoding with one of the composite surround systems. This would likely be the simplest and most cost effective method because it has the lowest impact on a station's studio and facility infrastructure (see Figure 2).

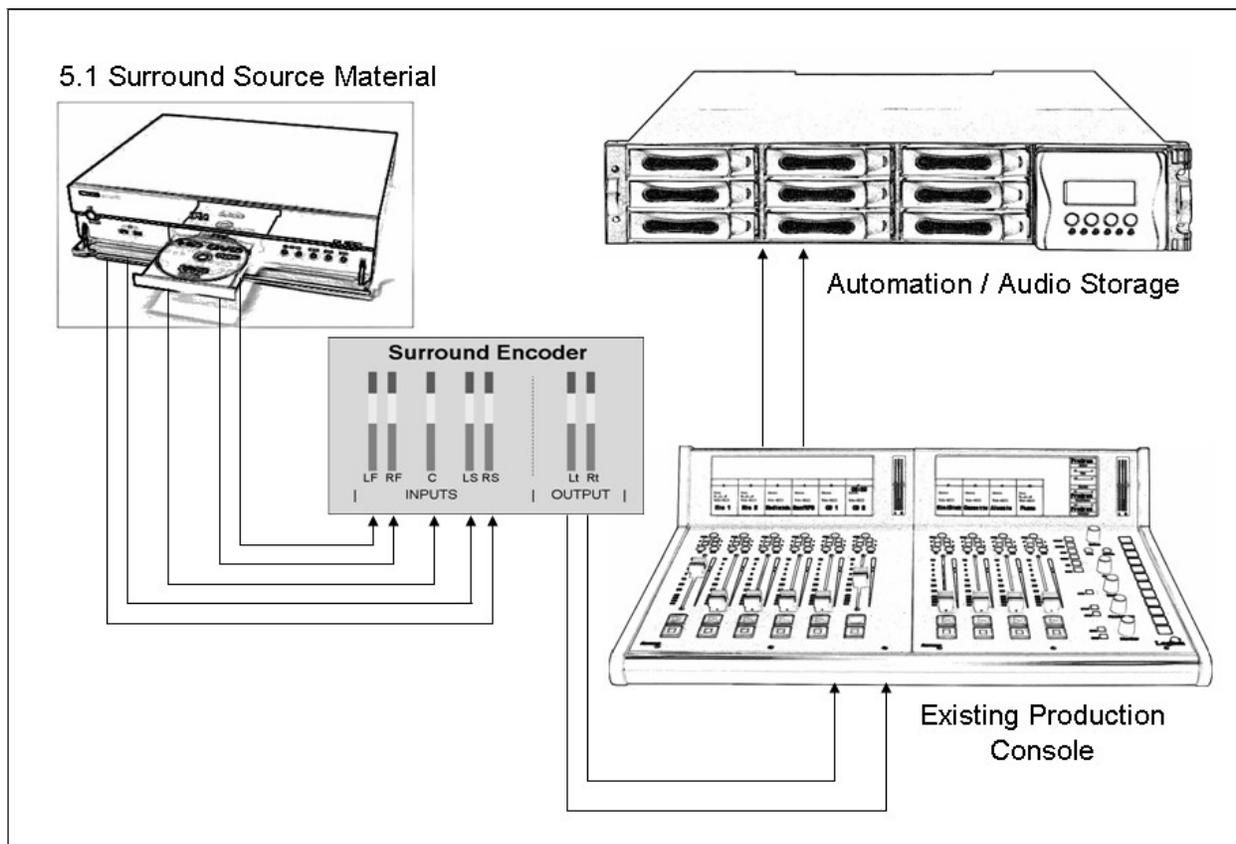


Figure 2. Music only – basic implementation

Implementation of this approach will only require the installation of a CD or DVD player or other source player with discrete 5.1 audio outputs, such as a digital audio workstation, and a surround sound encoder. The encoder converts the original 5.1-channel source material to a two-channel Lt/Rt signal, which is then stored in the automation/storage system. No further changes in the facilities or air chain would be required, although some additional changes may be desirable.

For example, upgrading the production and on-air control-room audio monitors to a 5.1 system (including a surround decoder of the format used for broadcast encoding) is recommended. This allows producers and announcers to hear and enjoy the surround experience, as well as know when a failure or problem occurs. The station might further consider the inclusion of decoders other than the format used for broadcast, available as alternate monitoring sources through the same speakers, to observe cross-compatibility of the station's signal.

Keep in mind that in an IBOC broadcast, the audio is delayed by approximately eight seconds, making it impossible to monitor the actual off-air signal in real time. It will therefore be necessary to purchase additional surround decoder(s) for the post-processing/pre-transmission program monitor feed to on-air control rooms' surround monitoring systems.

Producing local content in surround

As mentioned previously, if all that is broadcast in surround is a station's music programming, the service will not take advantage of what could be the most engaging and dramatic effects of broadcasting in surround – its local production elements. This is where the creativity and talent of a station's staff can differentiate the service from its competitors.

Equipping a station for local production in surround will require a more significant change in studio equipment than that required for music only. A station will need to dedicate at least one production room to the production of surround material. This may be as simple as installing a digital audio workstation with 5.1-channel capabilities, or a broadcaster may want to upgrade an entire room, including the audio console, to support a true 5.1 output mixing bus. (See Figure 3.) A broadcaster must also decide whether to start with just one production room for creating surround elements, or to convert all production facilities at once. This depends primarily on the financial commitment that station management is willing to make.

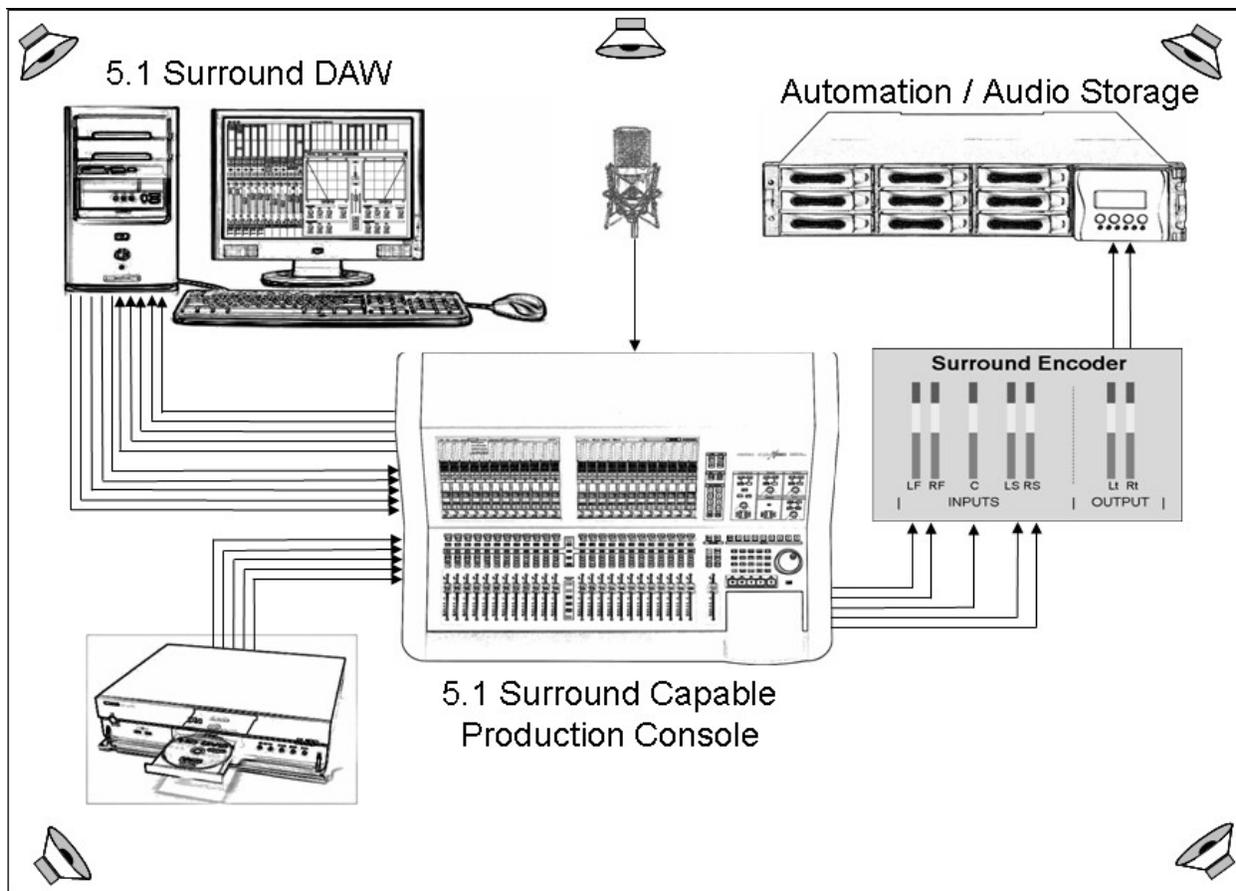


Figure 3. Full composite surround production room

If a studio is already equipped with a more modern “surface/router” audio system, it may already have the capacity necessary to be easily converted or reprogrammed to provide a discrete surround output. To see if this is the case, the manufacturer of the console and/or router should be consulted to see if this equipment can support the changes required for surround. If not, then this equipment may need to be replaced when converting to surround production.

Training should also be offered to the production staff members to teach them how to properly create and mix spots and other elements to sound natural in surround, yet still “jump out of the speakers” for the audience. Keep in mind that the better the tools provided to the station’s staff, the easier it will be to create a quality final product.

If a station decides to implement one of the composite systems for surround broadcasting, the output of the production room will (as with the music-only method) be passed through the surround encoder to create a Lt/Rt signal, which will then be stored and ultimately passed through the air chain. A surround decoder should also be installed in each production room, along with a 5.1 surround monitoring system. (Again, monitoring through multiple decoder formats may also be worthwhile.) It is important for the production staff to hear the final product the same way the listeners will before sending the produced spot to air.

The nature of composite surround systems dictates that an encoded and decoded composite surround mix may sound different than the discrete 5.1-channel mix originally sent to

the encoder. Thus it is helpful to “listen through the matrix” (i.e., monitor through an encode/decode loop of the chosen surround broadcasting format) when producing surround, so the discrete mix can be adjusted as necessary to produce the desired results after composite surround encoding.

Component and/or combination systems

The discussion above has focused on what is necessary to incorporate a composite surround system into a facility. What follows will consider the component method, described in Section 1 above. Component surround encoding (e.g., the MPEG Surround system) is a “digital only” surround system that is intended for use over a digital transmission path such as IBOC radio. In such an application, a station may also elect to simultaneously provide surround encoding to its analog signal via a composite system—a so-called “combination” approach. This is particularly helpful when a station blends from FM IBOC to analog FM, thus minimizing the effect of image shifting by avoiding a collapse into stereo when the surround-equipped IBOC receiver switches to the analog signal.¹³

In a component surround system, the surround product needs to be generated at the end of the air chain to provide perfect synchronization between the audio and data channels on an HD Radio signal. This means that the entire backbone of the studio facility must be in a discrete 5.1 format (see Figure 4). This will require the upgrade of not only production rooms, but also on-air control rooms, as well. Audio storage capacity will need to be evaluated, as well, and it may be necessary to increase the station’s hard drive space to accommodate storage of the 5.1 material.

Finally, it should also be noted that it is possible to use this same station audio architecture to feed a *composite* encoding system, if desired. In contrast to the simpler approaches described earlier (in which content is stored with composite surround encoding already applied), this approach would keep all audio in discrete multichannel form until broadcast, at which time composite encoding would be applied in real time—just as with a component system.

¹³ The MPEG Surround system by design can operate in a compatible mode where the stereo output is encoded for decoding by Dolby ProLogic decoders. In receivers equipped with MPEG Surround decoders, the full component surround quality is preserved.

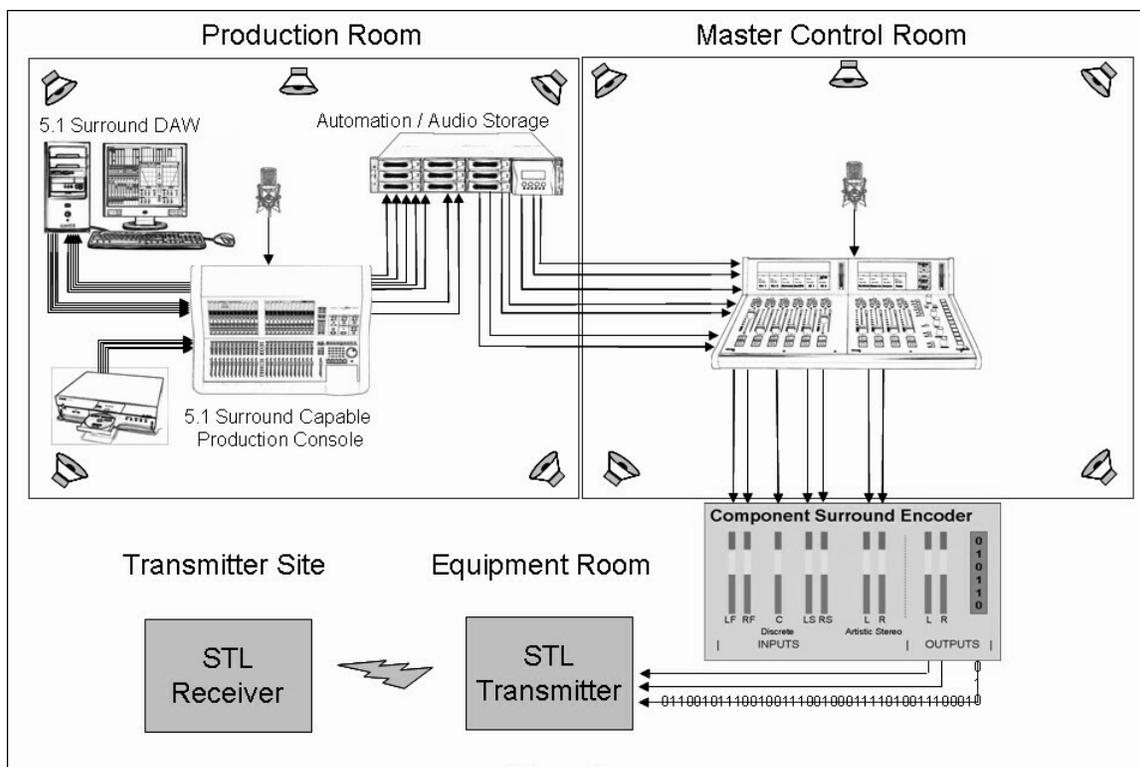


Figure 4. Component surround studio

For stations electing to use component surround encoding, it may be desirable to store all content in both 5.1- and 2.0-channel forms. The latter may be an artistic stereo version of the 5.1 content, or it may simply be a stereo downmix of the 5.1-channel mix. The 2.0-channel content may be fed to the analog side of an IBOC broadcast, or it may be used by a special feature of the MPEG Surround system, which allows an artistic stereo mix to accompany the transmission of spatial data from the 5.1-channel mix. (See Annex 2 for more detail.)

In these cases, eight discrete storage channels are required. A standard WAV file format for this type of storage has been proposed.¹⁴ This implies that the maximum capacity of a facility's existing storage, routing switchers and audio consoles may quickly be exceeded (although the trend toward IP audio infrastructures can reduce this impact, since it does not require discrete paths for each audio channel or pair, as in traditional analog or digital audio signal routing). It also creates the need for standard methods of ordering the channels throughout a facility, and their vigilant adherence. An error in patching a set of surround channels can be far more problematic to the resulting image than in a stereo environment, where the worst that can happen is that the stereo image is reversed.

A further challenge is presented when storing both a surround and artistic stereo mix of the same content, because the two release versions may not sync together. (More on this below under *Content Availability and Issues*.)

¹⁴ See Holzinger, Axel & Jonsson, Lars, *New File Format and Methods for Multichannel Sound in Broadcasting* (listed in Additional resources section below) for additional information.

Finally, because the component surround approach requires that discrete multichannel audio paths be retained so deeply into a station's air chain, numerous components (including audio processors and STL systems) must be able to support an increased number of audio channels. The latest design releases from iBiquity Digital may help resolve these complex issues, particularly the STL issues. For example, a broadcaster using iBiquity's new "Exgine" split system can keep audio processors and surround encoders at the studio and use a single data path to the tower to carry the encoded HD Radio signals to the exciter.¹⁵

Content availability and issues

Classical Music is by far the genre leader when it comes to number of titles available in a surround format. Classical encompasses 25-30% of all multi-channel titles. Rock/Pop is second, followed by Jazz. As of summer 2006 there are:

- 430 SACD labels, 3860 SACD titles (1,436 stereo only, 2,424 multi-channel);
- 115 DVD-A labels;
- Approximately 1,000 multi-channel DVD-A & DualDisc titles.

Using an average estimate of 12 songs per title, this indicates that over 40,000 songs are available today in discrete multichannel form.¹⁶

However, when applying these commercial releases to radio broadcasting, a number of unique and potentially thorny issues arise. They all center upon the issue of backward compatibility of the content itself – that is the ability for a surround mix as produced to downmix to stereo or mono with results that are aesthetically acceptable to the artist.

5.1/2.0 compatibility of content

Unlike today's stereo music content, which nearly always takes into account the possibility of monaural presentation, much of the commercially available surround music content is intended for playback *in surround only*. This is a feasible assumption because the release formats used to date (SACD and DVD) generally provide *both* a surround *and* a stereo version of the same material, as separate tracks. Thus it is intended that the 5.1 mix will be used only when 5.1 playback is available, otherwise the 2.0 version will be played. (The DVD-A format even includes a flag that disallows a DVD-A player from routing an internally generated 2.0 downmix of 5.1 content to the player's stereo outputs, and some artists are enabling this no-downmix flag on their DVD-A releases. Of course, this does not prohibit an external downmix to be made from the surround outputs of the player.)

So regardless how elegantly compatible the design may be for a surround/stereo/mono delivery or reproduction system, if the surround content itself is created in a fashion that does not downmix well, true compatibility is not achieved. (Similarly, the mono compatibility of the FM multiplex stereo system is foiled if the stereo content is produced with significant out-of-phase material – or presented to the matrix with a polarity reversal – between left and right channels.)

¹⁵ Additional information on the Exgine architecture is available on the Internet at www.broadcast.harris.com/product_portfolio/product_details.asp?sku=WWWflexstar, <http://bdcast.com/hierarchy/product.php?maj=104&sec=206&cls=317&prod=466>, and <http://www.nautel.com/ResourceCentre.aspx> (see IBOC Exgine/Exporter/Importer System Guide under Information Sheets).

¹⁶ (2,424 SACD titles) + (1,000 DVD-A/DualDisc titles) = 3,424 multichannel albums x 12 tracks per album (12 x 3,424) = 41,088 songs in multichannel format.

Thus there is a current disconnect between the music recording and radio industries, in that the current delivery products (DVD and SACD) have sufficient capacity to provide separate content versions, each optimized for 5.1 or 2.0 delivery, whereas broadcasters require a hierarchical format that provides a single content version compatible for listening in 5.1, 2.0 and 1.0 modes. At this writing, discussion is ongoing on possible solutions to this conundrum, but broadcasters should at least be aware of this important issue as they consider their broadcasting of commercially published surround music content.

As a point of reference, note that the cinematic and television industries generally have taken a different approach in their production of surround soundtracks, in which the downmix compatibility of 5.1 content to 2.0 and 1.0 presentation is always considered. So the music industry is taking a somewhat unorthodox direction here, although there are good technical and aesthetic reasons why a mix truly optimized for surround listening may not downmix well to stereo/mono (similar arguments were made regarding mono compatibility in the early days of stereo production). Thus a compromise approach will ultimately be required, just as has become the norm in the movie and TV businesses.

One possible solution currently being explored is the development of “artist-approved” downmixes by trusted third parties, who would work with artists and labels to provide this service, and offer the results to broadcasters and others for single-mix compatible distribution. In this scenario, the production facility is responsible for gathering approval from the artist/label to downmix their surround content to achieve the best result of the content. This allows for adjustments to be made appropriately to each surround selection so that the most desirable downmix is achieved. At this writing, such an option is being explored by the industry, and already undertaken by at least one surround format’s proponent for distribution of surround content to stations expressing interest in surround broadcasting.

Note also that regardless of the broadcast surround format used, some downmixing is inevitable. While the MPEG Surround format offers the possibility of extracting spatial data from a surround mix but transmitting the stereo mix of the same content, this is only possible if the two mixes are synchronous, and this is not always the case. (More on this below.)

Therefore, it is recommended that surround content always be checked for the suitability of its downmix in a controlled monitoring environment, and where appropriate that a manual, custom downmix be performed.

Downmixing options

Broadcasters have some options for how and when downmixing takes place. As noted above in the discussion of station architecture, one approach is to store all surround content in discrete form and encode into a composite or component surround broadcast format in real time as broadcast. In this case any adjustment to downmix parameters takes place in the air chain equipment, implying that global parameters are set, which apply to all content transmitted.

Another approach is to pre-encode surround content into its broadcast format upon ingest. This may save storage space, but it also allows more careful and specific setting of any downmix parameters (so-called “manual downmixing,” as recommended above), on a cut-by-cut basis, if desired.

Monitoring

Whether downmixing is performed manually or automatically, there are several standard algorithms that can be applied, or at least used for guidance by broadcasters (see next section below). Essential to the setting or verification of any downmixing is a monitoring environment

that allows high-quality listening to surround, stereo and mono audio. Ideally the stereo audio should only be played through two speakers (L, R) and mono should only be played through one speaker (C).

As noted above under *Producing Local Content in Surround*, it is essential in any such environment to monitor the surround audio through an encode/decode loop for the broadcaster's surround encoding format of choice. It may also be desirable to include *decoders* for other formats, to check how the station's surround signal will sound on surround receivers equipped with systems other than the station's chosen encoding format.

The same applies for any content created in surround (spots, remote concert recordings, etc.) by the broadcaster. During the recording or production process, the mix engineer should listen to the surround mix through an encode/decode loop of the station's chosen format, as well as check for acceptable results in the stereo and mono downmixes of the decoded signal.

Downmixing algorithms and techniques

Just as stereo is summed to mono by a simple and standard 6dB reduction in each of the stereo channels' level, so too are there empirical downmix algorithms for reducing surround signals to stereo (or mono). While necessarily more complex due to the number of channels involved, similar practice to stereo/mono summing is involved.

The most commonly referenced standard algorithm for downmixing of 5.1 to 2.0 and 1.0 is contained in Recommendation ITU-R BS.775-1. It provides the downmix instructions listed in Table 2. Note that the algorithm is actually a 5.0-to-2.0/1.0 algorithm. The LFE channel is not included, because it is expected that all main channels (including LS and RS) will be full-range, and if a subwoofer is used by the listener, its input will be derived from the main channels by the bass management system of the receiver. (In surround music mixing, it is rare that any unique content appears in the LFE channel; typically it is only a reinforcement of the same bass energy that appears in the full-range channels. Contrast this to cinematic audio, which occasionally includes some unique elements or audio processing in the LFE channel.)

For automatic downmixing, BS.775-1 is recommended (Table 2). For manual downmixing, it is also a recommended starting point, after which the downmixer may wish to make minor adjustments in the center and/or surround channels' contribution to the downmix, for example.

Table 2. The mix coefficients of Recommendation ITU-R BS.775-1, converted to typical mixing console attenuation settings

Downmix To	Output channel	Input attenuations				
		L	R	C	LS	RS
Stereo (2.0)	Left (L)	0 dB	∞	-3 dB	-3 dB	∞
	Right (R)	∞	0 dB	-3 dB	∞	-3 dB
Monaural (1.0)	Mono (C)	-3 dB	-3 dB	0 dB	-6 dB	-6 dB

Synchronization

As noted earlier, commercial music releases in surround are generally accompanied by a separate stereo mix version. This is often called the *artistic stereo* mix, specifically created by the artist, thus differentiating it from a stereo signal derived post-release (e.g., by the broadcaster or consumer) via downmixing the surround release – either manually or automatically – from 5.1 to 2.0.

It could be possible for a broadcaster to deliver the artistic stereo version over a station's analog FM service, while feeding the broadcast-encoded surround version over its IBOC MPS service. It is also possible using the MPEG Surround system to insert the artistic stereo version into the signal for broadcast, while deriving the spatial data from the surround mix. However, either of these techniques rely on the artistic stereo and surround release versions of a given content selection being synchronous, which is not guaranteed.

In one recent test, for example, it was found that over 20% of the selections exhibited timing differences between artistic stereo and surround versions, even when the both versions were extracted from the same release disc using a player that was synchronized to an external master clock. These differences ranged from fractions of a second to several seconds.

These timing differences can become further exaggerated when the artistic stereo version is extracted from an audio CD drive on a PC (a common practice at radio stations), while the surround version is ingested from a SACD or DVD player.

These timing differences can be attributed to numerous causes, including (but not limited to) the following:

- Different recording systems are used to record or master the artistic stereo mix and the surround mixes.
- Different production facilities are used for the artistic stereo and surround mixes, each having different studio master clocks, mixing and/or playback systems.
- Different artistic techniques or effects are used in producing the artistic stereo and surround mixes, which introduce subtle yet cumulative time delays on one version relative to the other, even though the same original performance master tracks may be used in both cases.
- Different audio extraction methods are employed by the broadcaster when ingesting the artistic stereo and the surround versions (e.g., 48 kHz vs. 44.1 kHz sampling rates, or poor-quality sampling rate conversion).

Note that DVDs and SACDs that include artistic stereo and surround versions of the same content are generally mastered without regard for such synchronization, and are distributed without guarantee of synchronicity. At this writing there are also no known end-user programs or playback-device features that can reliably extract audio from DVD and/or SACD and automatically time align artistic stereo and surround versions. At present, this must be done manually using a digital audio workstation.

Finally, there is also a growing trend toward the release of wholly different content (i.e., edits) in the surround and stereo versions of a given piece of content, making the two versions completely non-synchronous. For example, the same song on the same release may include a few measures or an extra verse in the surround version that do not appear in the stereo version.

For all of these reasons, broadcasters are cautioned against assuming that fully synchronous surround/stereo content will be available, and that the ingest process for

surround+stereo storage may be a fairly labor intensive (and not always successful) process. Thus broadcasters who wish to ingest content in this form may occasionally have to create the stereo mix by downmixing the surround content.

While there will likely be a continuing dilemma of providing the artistic stereo mix vs. a downmix to the stereo listener, there are some who feel that there is at least one benefit to downmixing, regardless of which surround delivery format creates it. This is due to the current practice in surround mixing that favors less of the heavy compression, limiting and/or clipping often present in today's artistic stereo mixes. While these effects are preferred by the artists in their stereo mixes, they can often cause unintended unpleasant results when they encounter the *additional* processing applied in some broadcast air chains.¹⁷

Thus the more lightly processed surround downmix of such content may avoid some problematic limiting and/or clipping issues when broadcast. Though this fact cannot be used to resolve the quandary of using an artistic stereo mix vs. a surround downmix for compatible stereo/surround broadcasting, it is one element for broadcasters to keep in mind when providing or encoding content, regardless of which surround delivery system is implemented.

¹⁷ See Foti, F. & Orban, R., *What Happens to My Recording When it's Played on the Radio?* (listed in Additional resources section below) for additional information.

3 Compatibility between surround systems

Currently there are several technologies that are either certified by or seeking certification from iBiquity Digital for the broadcast of surround content on HD Radio.¹⁸ Proponents of these same technologies have participated in the NRSC's SSATG. These technologies include (in alphabetical order) Dolby Laboratories *ProLogic II*, MPEG Surround, Neural Audio *Neural Surround* and SRS *Circle Surround*. Regardless of which technology is utilized, the existence of multiple systems necessarily presents the question of whether the systems are cross-compatible. In other words, if a broadcaster encodes surround content using one system, how will it decode for a listener using another system? Will the consumer experience the surround sound content satisfactorily under all such conditions?

Several of the aforementioned companies claim that their systems are cross-compatible. However, none of these companies have provided NRSC with test data verifying this. Therefore it is suggested that a broadcaster utilizing any of these technologies (or others that may become available) encode content with their prospective format of choice, and listen using other formats' decoders to determine whether the surround-equipped listener will experience multichannel audio content in the manner that the broadcaster intends.

When one is conducting a cross-compatibility test, the reference for comparison should be surround sound content that has been decoded by the same system that encoded it. It has been suggested that the reference for a cross-compatibility test should be the original surround sound content, but that would not provide true cross-compatibility data. The intent of checking cross-compatibility is to determine whether other technologies decode surround content in a similar fashion as the technology that encodes it, not to compare the decoded result to the original discrete content. The listener will not experience the original content, regardless of which technology is chosen for broadcast.

When comparing decoded signals, one should listen for spatial envelopment, imaging, timbre and clarity of the decoded surround content, and determine whether results are satisfactory.

Also, when conducting cross-compatibility tests, one should pay particular attention to the various playback modes of any decoder. For example, both Dolby Prologic II and SRS Circle Surround have a cinematic/movie mode and a music mode for decoding surround sound content. Both of these companies state that their decoders' default playback mode will be set differently depending on the environment, such as a home theatre vs. automotive equipment. Therefore, one should listen to all playback/decode modes that any format provides.

Further, the degree of cross-compatibility may change depending on what type of surround sound content is broadcast. For instance, it can be expected that the decoded listening experience will change depending on music genre (e.g., rock, pop, country or classical). Different surround content challenges each format in a different manner, so broadcasters should pay particular attention to the type of content that their stations are likely to utilize, and not assume that the formats will produce similar cross-compatibility results if the content type changes.

At this writing, results of the first surround format cross-compatibility tests are pending publication. These tests were conducted by the Audio Engineering Society's Cincinnati Chapter,

¹⁸ The iBiquity certification process is described in Section 1 of this report. Note that certification is not an absolute requirement. Broadcasters and receiver manufacturers are free to use both iBiquity-certified and non-certified surround sound technologies with IBOC systems.

in conjunction with Dr. Ellyn Sheffield of Salisbury University, NPR Laboratories, the Corbett Studio (Cincinnati, OH) and Sonic Arts (Cincinnati, OH). The tests were designed to show the extent to which one can expect surround content encoded by any one of the following systems to be reliably decoded by any other one:

- Dolby ProLogic II (described in Annex 1)
- Neural Surround (described in Annex 3)
- SRS Circle Surround (described in Annex 4)

The MPEG Surround system was not available at the time these cross-compatibility tests were conducted, so interested broadcasters are advised to pursue their own examinations of the cross-compatibility of that format with the others above, when the technology becomes available.

4 Surround sound and multicasting

Multicasting refers to the broadcasting of multiple audio programs within a single IBOC service. The IBOC FM system accommodates multicasting programs in two ways, utilizing either the Supplemental Program Service (SPS) or Advanced Application Services (AAS) features of the system.¹⁹ The reduction in audio program bit rate required for IBOC multicasting may have more of a subjective impact on a surround audio signal than on a stereo or mono signal.²⁰ This impact may also vary with the surround encoding format used.

The abovementioned acceptance of surround encoding formats for HD Radio use by iBiquity Digital considered the systems only at the full hybrid mode HDC bit rate of 96 kb/s. Broadcasters are therefore encouraged to conduct thorough evaluation of any candidate surround system(s) at all bit rates that are likely to be used, to determine whether acceptable performance (in surround, stereo and mono listening environments) is achievable in multicast applications with surround encoding.

Surround system manufacturers are encouraged to perform such multi-bit rate tests of HDC's effect on their formats, so they can readily provide broadcasters with useful data on the subject. In addition to consulting with surround system manufacturers, broadcasters may also want to confirm these results with their own tests using typical program material of their format(s).

¹⁹ Transmission of multicast signals is only considered practical over FM IBOC; the limited capacity of AM IBOC (36 kbps for hybrid mode) is not considered sufficient for multicasting.

²⁰ See Sheffield, E., *Perceptual Tests of iBiquity's HD Coder at Multiple Bit Rates* (listed in Additional resources section below) for additional information.

5 Impact on the analog signal

The FCC requires that broadcasters simulcast their main channel audio signal on the analog and (MPS) digital audio portions of the hybrid FM IBOC signal. This fact, combined with the fact that HD Radio receivers are designed to “blend to analog” (when the digital signal is weak or otherwise impaired), means that a broadcaster who decides to transmit the main channel digital audio signal in surround is likely to want to use surround for the analog audio signal, as well. In this section, some of the issues unique to the broadcast of surround over an analog FM signal are discussed.

Background

The analog FM stereo audio system has been operating successfully since 1961, and was designed to be backwards compatible with the mono-only system it followed. The left and right audio channels are summed to create a monaural signal that is received on mono radios. The two channels are also subtracted to create a stereo difference signal, which is broadcast along with the mono sum signal. From these two signals, the original left and right audio channels are recovered—adding them generates the left and subtracting them generates the right. This is expressed mathematically as follows:

$$L = 1/2 \{(L+R) + (L-R)\}$$

$$R = 1/2 \{(L+R) - (L-R)\}$$

Within the FM baseband, the $L+R$ signal resides between DC – 15 kHz as shown in Figure 5. The $L-R$ signal is transmitted on a subcarrier which utilizes double sideband suppressed carrier modulation (DSB-SC) of the $L-R$ baseband information. The 30 kHz frequency range is due to the double sidebands, and the subcarrier is centered at 38 kHz. This results in spectrum occupancy between 23 kHz – 53 kHz. The 38 kHz (suppressed) subcarrier is created by a 2X multiplication of a 19 kHz *pilot tone*. The pilot is also used for signaling a receiver that a stereo broadcast is present. The baseband signal shown in Figure 5 is frequency modulated onto the RF broadcast carrier signal using an *FM exciter*.

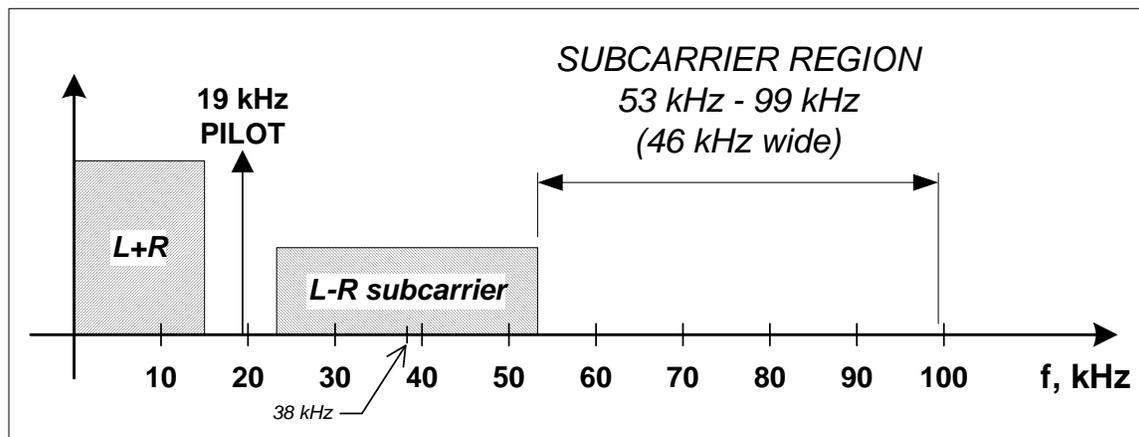


Figure 5. FM baseband illustrating $L+R$, pilot, and $L-R$ components

One of the shortcomings of FM transmission is its susceptibility to multipath distortion caused by the relative delay between signals arriving from multiple paths (between the transmitter and receiver) due to reflection by terrain or structures. The reception problems caused by multipath result from a number of factors, including audio processing, path length difference, presence or absence of subcarriers, the relative modulation level and placement (in frequency) of those subcarriers, as well as the performance of the receiver itself. Since a composite surround signal may sometimes increase the overall level of the (L-R) signal modulating the 38 kHz subcarrier, it can influence the susceptibility of the FM signal to multipath interference.²¹

Composite surround methods and multipath

The X-Y plots in Figure 6 were generated by connecting the Lo (or Lt) channel to the X input and the Ro (or Rt) channel to the Y input. This yields a pattern that is commonly used to measure phase differences between two signals.

As shown in the figure, the phase relationships between the stereo channels are different for the artistic stereo (Lo/Ro) and composite-encoded downmixed stereo (Lt/Rt) cases. Consequently, the behavior of the two different resulting FM stereo signals (either Lo/Ro or Lt/Rt) in a multipath fading environment may also be different.

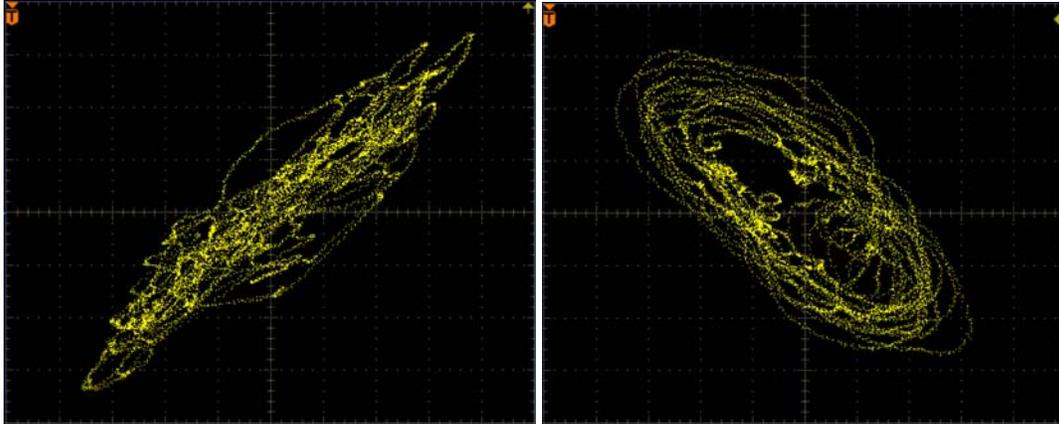
Keep in mind that not all programming material will produce the same results as shown in the examples in Figure 6 below. Example A actually depicts an extreme case and is presented here to show just how different the artistic stereo and composite-encoded signals can be. This is not typical of all surround audio mixes, and may vary when encoded and downmixed through different composite encoders.

Broadcasters who suspect an increase in multipath problems can make observations similar to the ones shown below to evaluate their program material. Even some artistic stereo recordings have been found to exhibit a display such as in the right side of Example A and may contribute to problems. Informal listening tests have also revealed that multipath effects can vary substantially from receiver to receiver. Thus there are many contributing factors to multipath on an FM signal.

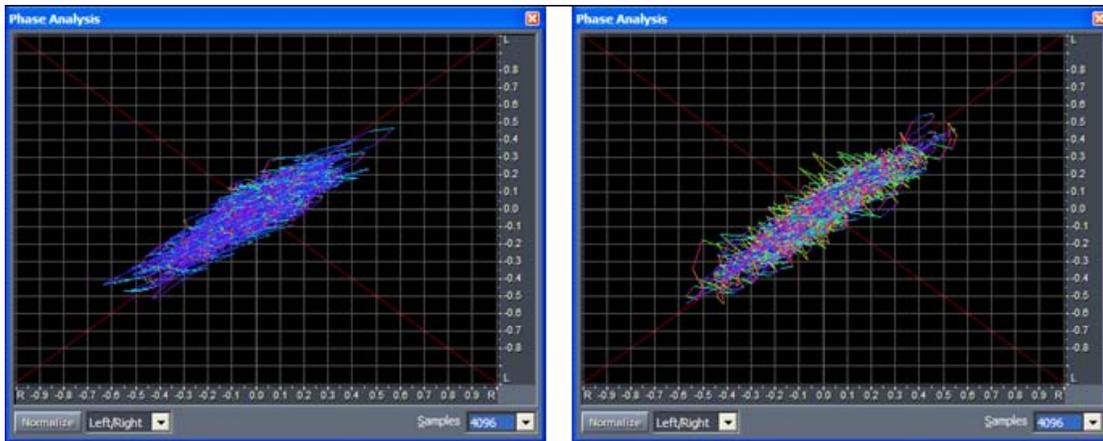
NPR Labs study on impact of composite surround signals on stereo analog FM

In the spring of 2006, NPR Labs made a series of audio recordings to characterize the reception behavior of composite surround sound stereo signals broadcast over a stereo analog FM signal in a laboratory environment. This study was developed as an aid to FM radio broadcasters who are curious about the impact of the surround sound information to analog stereo reception under conditions of multipath fading. This project produced recordings from FM receivers impaired by multipath, and the result of this study was a large set of audio files.

²¹ See, for example, the Bose and Short paper which offers a theoretical analysis of the many factors involved in FM performance in the presence of multipath, or Annex 5 for a review of the Bose and Short paper and examples of program material.



Example (A): Beach Boys, “Wouldn’t It Be Nice”



Example (B): Sting, “Fill Her Up”

Figure 6. X-Y Plots of two selected songs. In each example the trace on the left shows the artistic stereo (Lo/Ro), while the traces on the right show a composite-encoded downmixed stereo format (Lt/Rt).

The audio sources used in this study were selected from commercial music releases covering a variety of genres ranging from rock to classical music. Commercial multichannel recordings were matrix encoded with systems from SRS Labs, Dolby Laboratories, and Neural Audio. The matrix-encoded and artistic stereo versions of the samples were converted into hybrid FM signals (analog stereo FM and HD Radio carriers) for processing by an RF channel simulator. The test bed produced controlled amounts of fixed and mobile multipath impairment for reception by a home stereo receiver, an original equipment car radio and an after-market car radio. Audio from each receiver was digitally recorded and archived. Details of the test procedure, a table of all the test combinations and an index to the audio files are given in the NPR Labs report entitled *Compatibility of Matrix-Type Surround Sound Encoding Techniques with Analog Stereo FM Transmission Impaired by Multipath - Test Methodology and Description of DVD Audio Recording* (listed in Additional resources section below).

6 Testing surround system on your station

To effectively test surround sound for broadcast, the following equipment is recommended:

- *5.1 channel monitoring system:* This should consist of five identical full range speakers and a subwoofer. It may be possible to achieve this by adding three identical speakers plus a subwoofer to an existing stereo playback system. Monitors will need to be setup in a standard 5.1 configuration, with the monitoring specifications in ITU-R BS.775-1 recommended. (See Figure 1 above.)
- *5.1 channel monitor controller:* This device allows for trimming of gain settings for each speaker, a single gain control for overall level control, and the selection and routing of multiple multichannel, stereo and mono audio sources.
- *5.1 channel metering system:* It is important to observe both amplitude and phase within the 5.1 signal. The most common type of metering system for 5.1 surround is a “jellyfish” display (shown in Figure 7). Note that X-Y type displays (as shown in Figure 6) are designed for use with two-channel signals only.

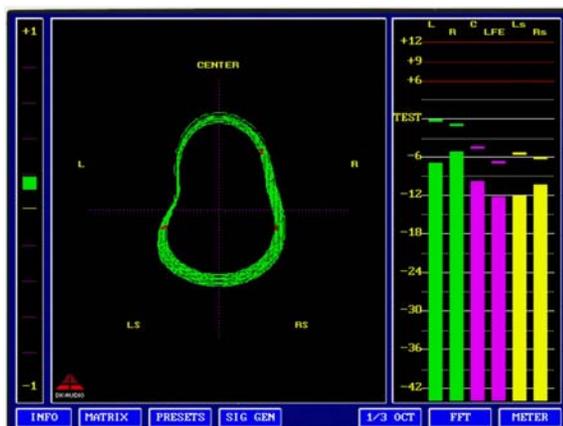


Figure 7. “Jellyfish” display showing amplitude and phase within a 5.1 signal.

- *5.1 channel encoding and decoding equipment:* Both encoding and decoding equipment are needed from any format(s) the station is interested in testing. As noted in Section 3 above, decoders from all other systems are also useful for verifying cross-compatibility.
- *5.1 channel reference material:* A wide variety of high-quality discrete 5.1-channel source material is needed to accurately evaluate the various multichannel broadcasting systems. Ideally, both DVD-A and SACD players should be available for any testing (or at least for the ingesting of content to a discrete multichannel-capable digital recording system or device).

7 Additional resources

- Bose and Short, *A Theoretical and Experimental Study of Noise and Distortion in the Reception of FM Signals*, IEEE Transactions on Broadcasting, Volume 47 No. 2, June 2001
- Breebaart, J., et.al., *MPEG Spatial Audio Coding/MPEG Surround: Overview and Current Status*, AES 119th Convention Paper 6599, 2005 October 7-10, New York, NY
- *Compatibility of Matrix-Type Surround Sound Encoding Techniques with Analog Stereo FM Transmission Impaired by Multipath - Test Methodology and Description of DVD Audio Recordings*, NPR Labs, October 17, 2006, available at <http://www.nprlabs.org/research/matrixsurroundmultipathcompatibility.pdf>
- Detweiler, J., *Conversion Requirements for AM and FM IBOC Transmission*, iBiquity Digital Corporation white paper, available at www.ibiquity.com/broadcasters/quality_implementation/iboc_white_papers
- Foti, F., *5.1 Surround Sound Compatibility Within HD Radio TM and The Existing FM-Stereo Environment*, May 2005, Omnia Audio white paper, available at www.omniaaudio.com/tech
- Foti, F., *The Killer App for FM: 5.1 Surround Sound*, 2005 NAB BEC Proceedings, pg. 41
- Foti, F. & Orban, R., *What Happens to My Recording When it's Played on the Radio?*, AES 111th Convention Paper #5469
- Herre, J., et.al., *The Reference Model Architecture for MPEG Spatial Audio Coding*, AES 118th Convention Paper 6447, 2005 May 28-31, Barcelona Spain
- Holzinger, Axel & Jonsson, Lars, *New File Format and Methods for Multichannel Sound in Broadcasting*, AES 118th Convention Paper #6376
- *ITU-R Recommendation BS. 775-1 Multi-channel stereophonic sound system with or without accompanying picture*, International Telecommunication Union, available at <http://www.itu.int/rec/R-REC-BS.775/en>
- Kean, J, *Host Compatibility Measurements for the Extended Hybrid Mode of IBOC Digital Audio Broadcasting*, NPR Labs, October 29, 2004
- *NRSC-5-A In-Band/On-Channel Digital Radio Broadcasting Standard*, September 2005 – available for download free of charge on the NRSC web page, www.nrscstandards.org/Standards/NRSC-5-A.asp

- Radio World Newspaper articles (generic web site for surround is at <http://www.rwonline.com/reference-room/surround/index.shtml>):
 - *5.1 Implementation in the Real World*, Robert Reams, August 11, 2004
 - *Frank Foti Says Radio Needs the Real Thing, Not Synthesized, Matrixed or Compromised*, Frank Foti, October 6, 2004
 - *SRS Labs Surround Sound Will Work With HD Radio*, Alan Kraemer, November 3, 2004
 - *NPR Tries Out Surround Sound In New Year's Eve Broadcast*, Leslie Stimson, December 15, 2004
 - *5.1 or 2.0 Channels: Why Not Both*, Mike Pappas, January 5, 2005
 - *Neural Exec Says Stations Need an Upgrade Path That Works With Existing Equipment and Content*, Robert Reams, January 19, 2005
 - *Surround Sound Gear Introduced at CES*, Leslie Stimson, February 16, 2005
 - *A Look Back at Surround's Development While Radio Was Avoiding the Technology*, Skip Pizzi, February 16, 2005
 - *Surround: One Small Step for a Radio...*, Skip Pizzi, March 2, 2005
 - *Telos/Omnia Wants to Know More About Neural System, Tests*, Steve Church & Frank Foti, March 16, 2005
 - *Surround Sound Debate Abounds*, Daniel Mansergh, April 13, 2005
 - *Neural Audio Co-Founder Responds to Questions Posed by Steve Church, Frank Foti, Robert Reams*, April 13, 2005
 - *Commentary: Matrix Surround Systems Work*, Alan Kraemer, May 13, 2005
 - *Surround Sound Systems Debated*, Leslie Stimson, May 25, 2005
 - *Telos/Omnia Disputes Criticism of Studio Costs And Questions Statements by Neural Audio*, Steve Church and Frank Foti, June 8, 2005
 - *Creating Compatible Content for Surround Radio May Be Challenging*, Skip Pizzi, July 6, 2005
 - *The Architecture of Spatial Coding*, August 17, 2005
 - *Surround Is Part Entertainment*, Alan Kraemer, September 28, 2005
 - *At WGUC, Eager for Radio Surround*, Rich Rarey, October 26, 2005
 - *Where does Surround Sound Fit Into the Digital Jigsaw Puzzle?*, Steve Lyman, October 26, 2005
 - *Commentary: APT has its own take on surround*, Jon McClintock, December 7, 2005
 - *XM to Add 5.1 Surround Sound*, Leslie Stimson, February 15, 2006
 - *Surround Compatibility Revisited*, Skip Pizzi, March 29, 2006
 - *Surround, Past, Present and Future*, Robert Reams, March 29, 2006
- Reams, Robert, *Neural Audio White Papers*:
 - *5.1 Components in a 2.0 Broadcast Chain: A Brief Overview* (January 2, 2004) http://www.neuralaudio.com/downloads/5.1_Broadcast_Chain.pdf
 - *5.1 & 2.0 Interspersion: A Reality* (April 10, 2004) http://www.neuralaudio.com/downloads/5.1_Interspersion.pdf
 - *2-D Downmixing and Rendering as an Alternative Method of Transporting 5.1* (October 12, 2004) http://www.neuralaudio.com/downloads/Downmixing_and_Rendering.pdf
 - *Cognition, Ballistics and the Spatial Environment Engine* (February 1, 2005) http://www.neuralaudio.com/downloads/Ballistics_of_Cognition.pdf
 - *Discrete vs. Matrix: What Do the Words Mean?* (June 20, 2005)

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- http://www.neuralaudio.com/downloads/Discrete_vs_Matrix.pdf
 - *Downmixing: Blasphemy or Necessity?* (October 25, 2005)
http://www.neuralaudio.com/downloads/Downmixing_Blaphemy_Necessity.pdf
 - *Rendering: the Other Upmixer* (March 26, 2006)
http://www.neuralaudio.com/downloads/New_Rendering_is_Different.pdf
 - *Rendering: How it works* (April 10, 2006)
http://www.neuralaudio.com/downloads/Rendering-How_it_Works.pdf
 - *Universal Downmixing* (July 10, 2006)
http://www.neuralaudio.com/downloads/Universal_Downmixing.pdf
 - *Report on MPEG Spatial Audio Coding RM0 Listening Tests*, Audio Subgroup, ISO/IEC JTC 1/SC 29/WG 11, paper N7138, April 2005, Busan, Korea
 - Radio Magazine articles:
 - *Sound All Around*, Chriss Scherer, November 1, 2004
http://beradio.com/mag/sound_all_around/
 - *Practicalities of Surround*, Chriss Scherer, August 1, 2005
http://beradio.com/eyeoniboc/radio_practicalities_surround/
 - *Effective Sound Monitoring*, Alex Kosiorek, November, 2005
http://beradio.com/monitoring/radio_effective_surround_monitoring/
 - *Big, but not so easy*, Mike Pappas, February 1, 2006
http://beradio.com/features/radio_big_not_easy/
 - *The Art of Surround*, Alex Kosiorek, February 1, 2006
http://beradio.com/eyeoniboc/radio_art_surround/
 - Rödén, J., et.al., *HDC Surround, 5.1 Surround over HD Radio*, 2005 NAB BEC Proceedings, pg. 49
 - Sheffield, E.G., *Perceptual Tests of iBiquity's HD Coder at Multiple Bit Rates*, NPR Labs, October 14, 2004
 - Sheffield, E.G., *Report on Perceptual Tests of Coders at Low- and Very Low-Bit Rates*, NPR Labs, (October 2004)

Annex 1 – Dolby ProLogic II
Report submitted by Dolby Laboratories

Dolby Pro Logic II for HD Radio

1. Overview

Dolby Pro Logic II is a format that enables the production and delivery of multi-dimensional soundtracks for television, cable, consumer video, compact disc, video game and other stereo media. As defined in Section 1, Dolby Pro Logic II is a *composite surround format*, purposely designed to enable stereo facilities to seamlessly carry surround sound. That is indeed the case. Programs that are to be broadcast in surround can be easily encoded and merged into the stereo infrastructure along with any other stereo elements, layered with voice-overs, mixed with sound effects, cross-faded with adjacent content, uplinked to the transmitter, then broadcast as usual. As a result, the optimal signals to feed the HD Radio transmitter and the parallel FM transmitter are one in the same signal from the Pro Logic II encoder, thereby ensuring the best overall match when blending between these signals.

Consumers with conventional stereo or even monophonic playback systems have already been listening to fully-compatible Dolby Surround signals for decades, and Pro Logic II carries that legacy forward. And due to the ability of other composite surround decoders to handle Dolby Pro Logic II signals, compatibility of the broadcast signal extends to every conceivable type of consumer system—mono, stereo, or surround. Consumers with Dolby Pro Logic and Pro Logic II systems will best experience the program's spatial dimensionality, just as they have enjoyed from thousands of Dolby Stereo movies on video and television.

Upgrading a stereo radio broadcast facility to handle Dolby Pro Logic II content requires minimal changes to plant and practices. The same practices used to deliver high quality stereo will also be very effective in delivering high quality surround. The judicious use of dynamics processors and limiters is recommended, and any stereo effects processors must either be avoided, or checked beforehand to make sure they cause no unintended side-effects on the surround reproduction. Any processing applied to surround encoded signals must be applied equally to both left and right channels.

Surround monitoring may be done in real time from the final production feed, using a surround system in place of the normal stereo monitors. If this is not practical, an acceptable alternative would be to pre-qualify the end result of the overall production chain with

representative surround content monitored in a full surround system. In that case, the production monitoring can remain in stereo as usual, doing spot checks in other locations to verify the surround effect remains as expected. This may impose the least burden for the front-line staff. However, if there are any additional audio processors in the chain after that point, such as in the STL, additional monitoring of the off-air signal is also advised.

2. Surround programming

It is expected that a primary source of content will come from pre-existing 5.1 programs. Another option would be to create content at the studio in a 5.1-channel environment. And while such 5.1-channel recordings may be archived in discrete form for future use, it may be convenient to directly encode them into Dolby Pro Logic II and merge them into the facility's stereo infrastructure.

A third option for the radio station would be to continue to create local content in its existing stereo production suite, but monitoring through a Dolby Pro Logic II decoder. Many of the production tools used to enhance the spatiality of stereo productions are well suited to effective surround production. It's all in how and to what degree the tools are used—and the only way to judge the end result is to monitor in surround. One may well find that existing stereo program elements, particularly music, decode to surround nicely without further modification, and these may be incorporated into the mix directly. The use of a Pro Logic II encoder, of course, opens doors to an expanded palette of surround effects, but that doesn't preclude well-made, surround-proven stereo content from bringing useful benefits to the surround broadcaster, especially when used to supplement the primary surround programming.

As the advertising industry has long recognized the benefits of surround encoding, any of those spots coming to the station in Dolby Surround form will automatically blend seamlessly with other surround content to deliver their full effect to the listener, adding value not only to the station's surround effort, but to its clients as well.

The process of producing surround mixes is a topic unto itself, beyond the scope of this paper. We would refer those interested to see the following for further information.

http://www.dolby.com/assets/pdf/tech_library/44_SurroundMixing.pdf

http://www.dolby.com/assets/pdf/tech_library/214_Mixing%20with%20Dolby%20Pro%20Logic%20II%20Technology.pdf

3. Dolby Pro Logic II encoding

The Pro Logic II encoder combines five input signals—Left, Center, Right, Left Surround (Ls), and Right Surround (Rs)—into the matrix-encoded, two-channel Lt/Rt (Left total, Right total) delivery signal. The encoder is a straightforward but well-defined way to downmix multichannel audio to stereo. The encoder algorithm has no dynamic signal processing, sharp filters, or anything else that might color the tonal balance or impair the sonic purity of the source material, thus ensuring a high quality stereo signal.

As more radio broadcasters adopt Pro Logic II encoding, two independent studies were conducted in 2005 by the IRT and ZDF in Germany to compare the subjective quality of Pro Logic II encoding relative to standard ITU downmixing. Both organizations found virtual equivalency. Günther Theile of IRT summarized it well, saying there is no reason not to use Pro Logic II encoding for stereo transmission, as there are no draw-backs for stereo listeners, but major advantages for those decoding through Pro Logic II.

Pro Logic II encoding is also compatible with the installed base of Pro Logic decoders. Signals encoded to Ls will come predominantly from the mono surround output as expected, but also at a lower level from front Left output. The same happens for Rs encoded signals. Specific design parameters of the encoder were chosen to achieve the best subjective effect, thus allowing the original Pro Logic decoder to offer a hint of the stereo surround effects. As a result, recordings made with Pro Logic II encoding are not merely compatible with Pro Logic playback, they often sound better than recordings made with the original Dolby Surround encoder.

As shown in Figure 1, the Left and Right signals entering the encoder pass directly through to the Lt and Rt outputs with no alteration. The Center input is split equally to Lt and Rt, forming a perfect phantom center signal. The Left Surround input is also carried on the Lt and Rt outputs, but weighted more heavily toward Lt, and phase encoded ± 90 degrees. The Right Surround input is handled in similar fashion.

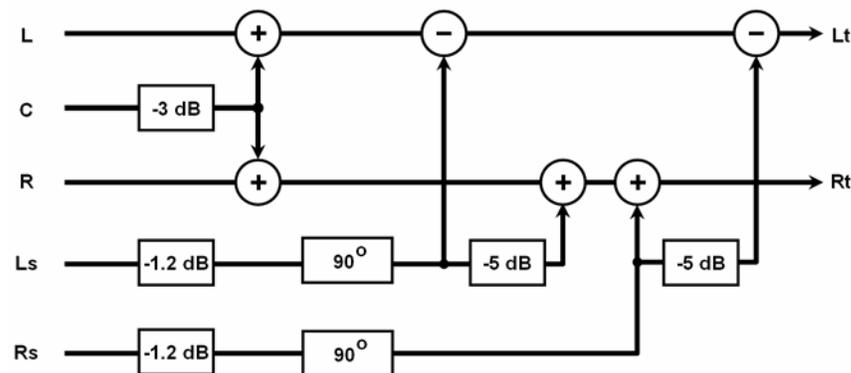


Fig. 1. Dolby Pro Logic II encoder process.

The output is a two-channel signal that has all of the attributes of a conventional stereo program, but, when called for by the source material, is able to convey defined surround

information to the Pro Logic II decoder, thus enabling the decoder to provide a controlled and predictable surround effect. This is all accomplished with no need to reduce the transmitted audio bitrate to deliver side chain data.

The benefit does not stop with the surround listener, however, as the spatial information imparted by the Pro Logic II encoder also creates a subtle, yet discernable benefit when listening in stereo. It has been found that when listening to 5.1-channel music recordings “automatically” downmixed to stereo by a DVD-A player, compared with the separate artistic stereo mix, the auto-downmix sometimes sounds flatter, with less depth, and hence can be less involving. When a stereo mix is made in the studio, the mixing engineer has at his disposal a wide array of sophisticated signal processors that can help make a stereo presentation more spatially interesting. Those tools may not be used as much when mixing a 5.1-channel program, so the downmixed surround signals fold straight into the front signals with no unique spatial identity. While the Pro Logic II encoder has no flangers or reverbs, the phase encoding does enable the stereo presentation to convey a pleasant spatial feel from the program’s surround signals, an effect that is directly proportional to the strength of the surround signals in the source 5.1 mix, which is therefore not inconsistent with the artist’s intent.

4. Dolby Pro Logic II decoding

Introduced in 2000, Pro Logic II represents a clear step beyond original Dolby Pro Logic, whose development was aimed primarily at playback of Dolby Surround encoded programs. In contrast, Pro Logic II was designed by the renowned inventor, James Fosgate, as the culmination of his 25-year quest to perfect surround processing aimed first and foremost at the challenging task of extracting a convincing surround effect from the vast array of stereo music recordings in the market. Once that was achieved, it was relatively straightforward to adapt the technology to optimally handle Dolby Surround programs. The result is a decoding technology that offers five full-range channels (including true stereo rear channels), advanced steering logic for maximum channel separation, and an exceptionally stable soundfield whether decoding stereo or surround encoded programs.

The widespread success of Pro Logic II decoding therefore was based not on an abundance of Pro Logic II encoded content, for there was none in the early days, but on its excellence as a versatile processor for virtually any two-channel material extant. Besides the Movie mode, Pro Logic II introduced a Music mode that not only allows consumers to better enjoy conventional music recordings in their surround systems, it allows them the flexibility to tailor the end result to their taste in three respects—center image width, front/back spatial dimension, and a panorama mode to wrap the L/R stage around the listener.

As in Pro Logic, the audio path in Pro Logic II, shown in Figure 2, is not a series of cascaded or complex signal processes, but single stages of wideband variable gain, arranged in parallel, to create the steering signals which are passively summed into the main signal path.

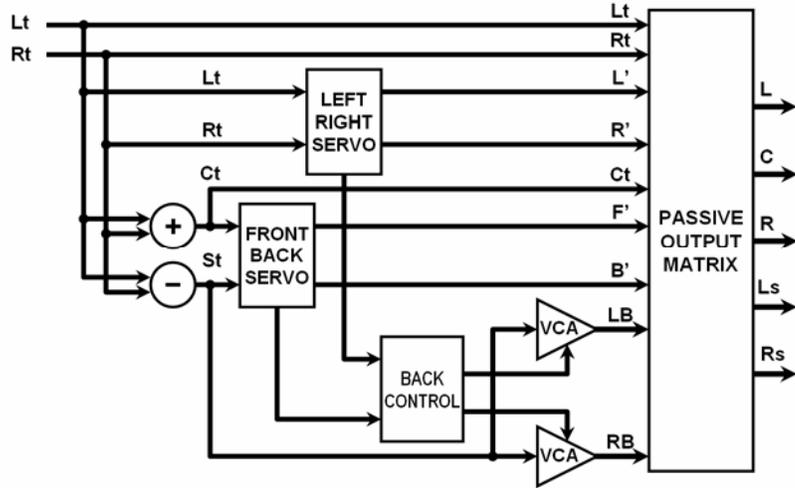


Fig. 2. Pro Logic II decoder.

Coupled with the newly patented servo logic control technique shown in Figure 3, which exhibits optimal dynamic behavior over the diverse universe of audio recordings, the end result is a surround processor boasting a level of sonic fidelity suitable even for the highest quality source material, heard by audiophiles in revealing playback environments.

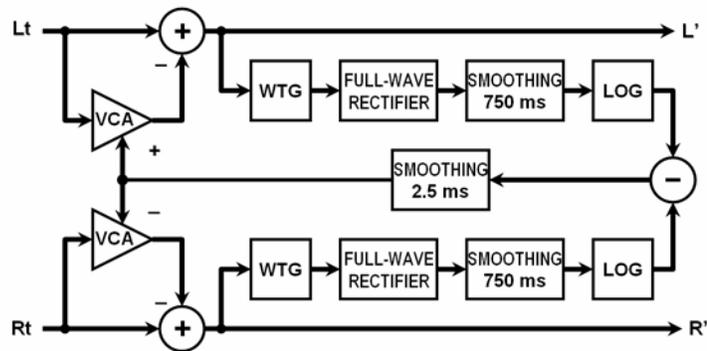


Fig. 3. Pro Logic II Front/Back Servo and VCA structure.

Dolby Pro Logic II is incorporated into nearly every Dolby Digital home theater system, and is included in increasing numbers of premium automotive surround systems from Volvo, Jaguar, Aston Martin, Land Rover, Acura, BMW, and various other makers in future. As of mid 2006, some 200 million Dolby Pro Logic decoders and 50 million of the newer Pro Logic II decoders have been sold worldwide into homes, cars, and PCs.

5. HD Radio and bitrates for surround

Enjoyment of a surround experience is not defined solely by the spatial aspects of the presentation. Overall fidelity is of paramount importance in order to draw listeners into the

artist’s vision. A station announcing its support of Dolby Surround will be alerting consumers that it is serious about sound, and they will automatically expect to hear better quality, free of obvious coding artifacts or other sonic impairments. Digital reception alone may not be sufficient to hold today’s iPod-equipped audiences.

Naturally, use of the highest transmission bitrates possible is recommended to achieve the best sonic experience for the overall HD Radio audience, whether listening in stereo or surround. Delivering Dolby Pro Logic II content makes no additional demands on bitrate, per se, as the surround encoding can survive very low coding bitrates. And while it is generally recognized that applying surround decoding to stereo programs improves the enjoyment of the audio, it does so in terms of spatial properties such as directionality and envelopment. No surround decoder, composite or component, can improve the sonic fidelity of the program material it receives, and they may sometimes help expose coding artifacts in marginally coded programs. When consumers watch television at home or listen to music in cars, they are not always seated in the ideal “sweet spot” where all the acoustic contributions of the surround presentation converge in equal measure. Sitting nearer the left speaker during a talk show, for example, can elevate the audibility of coding artifacts, since that’s all that remains in the L/R front speakers when the decoder steers the dialogue to the center. This is the well known phenomenon referred to as coder unmasking.

While there are multiple subjective factors involved in judging sound quality, Dolby’s general assessment of bitrate vs. quality for HD Radio is:

Good	48 kbps
Better	64 kbps
Best	96 kbps

Dolby does not recommend associating its surround trademark with bitrates below 48 kbps.

6. Radio consumers

Looking at the broad base of consumers, it is probably fair to say that the majority of FM radio users in cars and homes may be described as casual listeners, as opposed to audiophiles listening in an ideal playback environment. Radio is a welcome companion when doing household activities or driving or the like. We expect HD Radio customers will fit the same mold. This by no means implies that casual listeners would not appreciate HD Radio’s cleaner sound and noise free reception, nor does it mean they will not enjoy hearing surround sound. But it does suggest that the performance aspects of various surround systems ought to be weighed in light of how typical consumers will experience HD Radio in their lives.

We’ve already discussed the importance of sonic fidelity to the surround listener. How important is the spatial presentation? Would HD Radio be more compelling if it delivered 5.1-channel programs from DVD-A or SACD with perfect channel separation? Since none of the proposed surround systems are true discrete formats, this is a moot point. Rather, it is a question of what degree of spatial accuracy is meaningful in the HD Radio market.

Some newer cars have already adopted DVD-A systems, allowing surround music recordings to be heard with a high degree of accuracy and fidelity—the 5.1 discrete source is delivered directly to the 5.1 speaker system. It should be a perfect presentation for the listener. Unfortunately, that conclusion is incorrect.

Car seats are not located in the ideal position relative to the speakers. Programs mixed with vocals in the center channel will appear from the middle of the dashboard, while programs mixed with L/R phantom center vocals will appear from the closer speaker, and programs mixed with vocals in all three channels will image somewhere in front of the listeners. Even if a consumer likes one of these three variants, there is no consistency from program to program. What sounds correct and consistent when seated in the perfect sweet spot of a proper home playback system often becomes a distraction in a car.

Preventing that distraction, improving the imaging consistency of the spatial presentation, would thus not be a shortcoming of a car surround system for its lack of accuracy, but an attribute. Such consistency is inherent in the Pro Logic II system, which allows OEM system designers to tune the frontal soundstage exactly as they want it in the car, and it stays there whether the program is surround, stereo, or mono. This is in fact more consistent with the content maker’s intentions than the results heard from discrete formats when sitting off-center, either in a car or at home.

To the extent that 5.1 sources such as DVD-A may continue to exist, foibles and all for car playback, it is indeed possible to carefully post-process these signals to correct the imaging inconsistencies. But it takes considerable processing to do this properly—it is not a simple cross-mixing circuit. If such modification of the program is not only deemed permissible, but desirable, in order to achieve a better result for the listener, the issue of “accuracy to the 5.1 source” is not a relevant metric in evaluating a surround system for HD Radio. In addition, it would seem to be counterproductive to deliver sound in a format that requires such signal modification when it is more efficient and cost-effective to do so with a system that avoids the problem altogether, and is better suited to consumers’ needs.

7. Professional products

The professional studio encoder and reference decoder products are shown below.



Fig 4. Dolby DP563 Pro Logic II professional encoder.



Fig 5. Dolby DP564 Professional decoder.

More information on these products is available at the Dolby website:

http://www.dolby.com/professional/pro_audio_engineering/dp563_01.html

http://www.dolby.com/professional/pro_audio_engineering/dp564_01.html

8. Summary

Dolby Pro Logic II is best able to ease the transition of a broadcast facility from stereo to surround. It offers:

- Seamless integration with the stereo infrastructure
- Compatibility with stereo production practices for voice-overs, cross-fading and mixing with other stereo or pre-recorded surround spots
- Superb balance of surround sound qualities that satisfies a wide range of real world listeners and conditions
- Huge and rapidly growing installed base of surround decoders
- Well known brand signifying high quality sound for consumers

Annex 2 – The MPEG Surround Codec

Report submitted by Fraunhofer IIS



Fraunhofer
Institut
Integrierte Schaltungen

Technical Bulletin

Contribution to
National Radio Systems
Committee
Surround Sound Audio
Task Group Paper:

The MPEG Surround
Codec

1 Forward

Fraunhofer IIS is pleased to submit the following information on the MPEG Surround Codec and its application to HD Radio broadcasting to the National Radio Systems Committee Surround Sound Audio Task Group for its use in preparing a paper on the issues encountered in deploying surround sound.

2 The MPEG Surround Codec

MPEG Surround is a coding standard that compresses a multi-channel audio signal into a spatial representation plus a downmixed stereo or mono audio signal. It uses proven techniques to encode the spatial sound field into parameters that can be sent at typical bitrates of 5 to 16 Kb/s. An MPEG Surround decoder mixes the stereo or mono audio signal into each reproduction channel with amplitude, delay, and correlation specified by these parameters to reconstruct the surround sound image.

Unlike prior "matrix" surround systems, this is not a simple mixing in the time domain, but is done in critical hearing bands in the frequency domain, just as is done with stereo signals in compressed audio codecs such as AAC or HE-AAC. This allows the limitations of human hearing to be exploited to reduce the data rate required for the spatial parameters.

The MPEG Surround data rate can be varied depending on the spatial image quality desired. At very high bitrates, say above 32 kb/s, the codec becomes equivalent to discrete multichannel channel transmission. At bitrates below the nominal 5-16 Kb/s, the codec still performs significantly better than matrix encoding.

As a spatial codec, MPEG Surround is independent of the audio codec used for transmitting the stereo or mono audio information. AAC, MPEG-1 Layer II (For European DAB), or the iBiquity HDC codec may all be used.

3 Background of MPEG Surround

Since the development of the MPEG-1 codecs, MPEG audio codecs have compressed stereo signals into monophonic ones in the higher frequency bands when it is beneficial to do so. This technique is termed "intensity stereo" and relies on describing the level and time differences between the channels in a set of frequency band parameters sent with the mono frequency coefficients.

With the developing interest in surround sound transmission, the MPEG committee decided to investigate whether improved versions of these techniques could be used for compressing multichannel content. MPEG issued a Call for Proposals in March 2004, leading to four submissions. Upon their evaluation, MPEG decided that a combination of the two best proposed systems, one from Fraunhofer and Agere Systems and another from Coding Technologies and Philips, would be used as an initial reference model for standardization. This model was further developed into MPEG Surround, and tested to verify that it provides "sound quality substantially surpassing existing matrixed surround solutions, even for the transmission of a mono downmix signal or for spatial cue bitrates as low as 6 kbit/s." As a result, MPEG Surround was approved as a Final Draft International Standard in July 2006.

4 MPEG Surround Principles and Operation

Spatial compression codecs work by analyzing the sound image in terms of time and amplitude differences between channels, and the correlation between them. In a sound image, a listener will localize sounds through time differences due to the difference in propagation delay from the sound source to each ear, and through level differences between ears due to attenuation from diffraction around the head or shading of the sound by the outer ear or pinna. It is also possible to describe sound

sources in terms of their width or spaciousness – whether they are a point source or a more diffuse one – by describing the coherence or correlation of the signals reaching the ears.

By describing sound sources through these characteristics, we can separate the sound's location in the sound image from its actual acoustic content. The location parameters can be sent at much lower bitrates than could be obtained by compressing multiple audio channels.

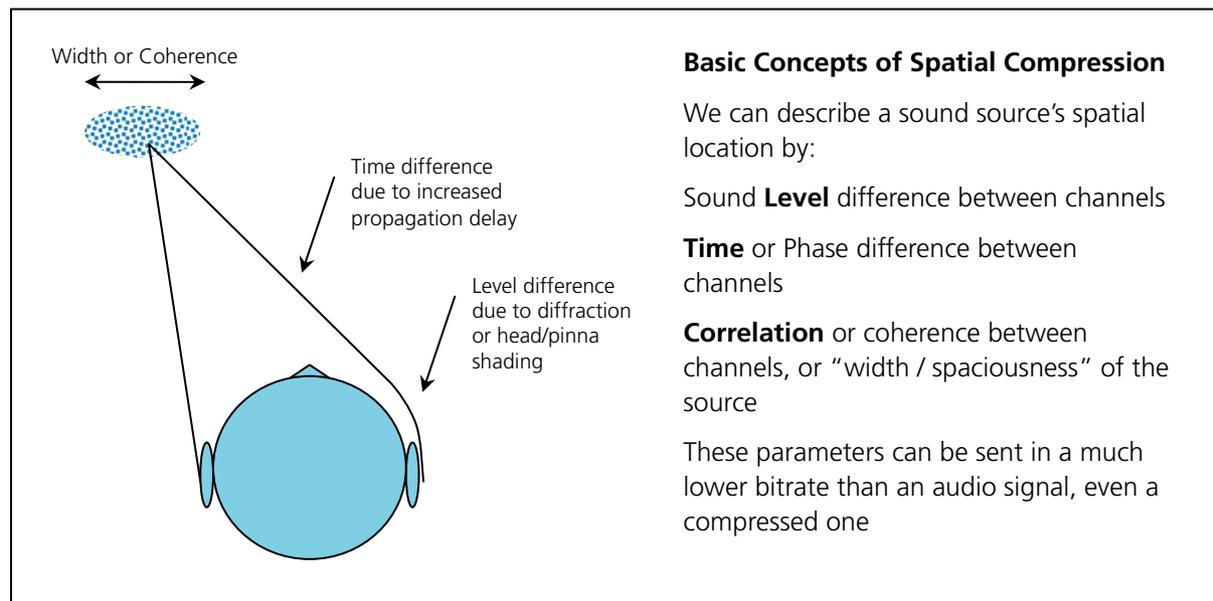


Figure 1. Spatial Compression Parameters

The acoustic or musical content of each channel can then be down-mixed into a stereo or mono signal for transmission. At the receiver, the mono or stereo signal is then mixed back into multichannel form according to the transmitted location parameters. Since all the content from each channel is present in the downmix, a simplistic way to consider the decoding process is to think of it as a bank of panpots as in a mixing console, that are dynamically adjusted to map the stereo mix back into multichannel surround.

Of course, this simplistic concept, which is similar to the operation of "steering" in a matrix decoder, will not work well with multiple sound sources. Actual spatial audio decoders are more complex, operating in narrow frequency bands to take advantage of limits on the ear's perception, and introducing adjustable decorrelators to control the width of the image. There is also smoothing of parameters to hide jitter in position resulting from quantization and processing to preserve the sound image during acoustic transients.

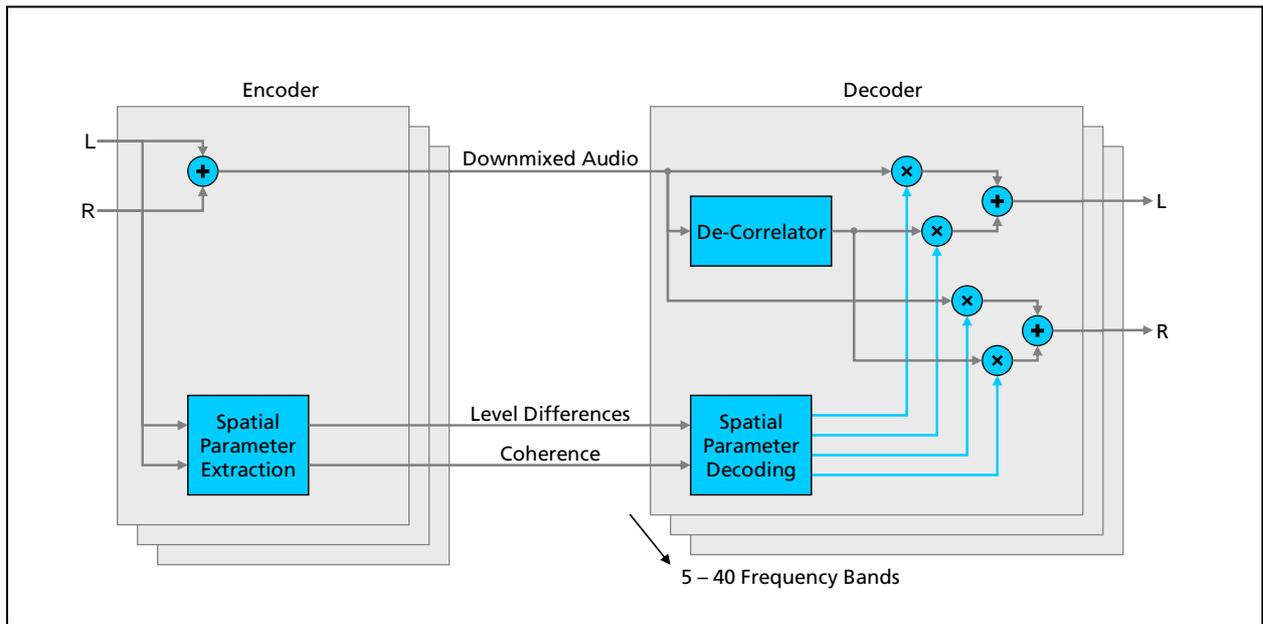


Figure 2. Simplified Stereo Example. Here a stereo signal is down-mixed to a mono one, while the level and coherence spatial parameters are extracted in the encoder. In the decoder, these parameters are used to re-mix the signal back into stereo. A de-correlator output is mixed in to add width or spaciousness that is lost in the mono mixdown.

An example of this process for a stereo signal is shown in Figure 2 for the MPEG Surround codec. In the encoder left and right channels are down-mixed to mono, and the level and coherence parameters are extracted from the input signal. In the decoder, we use these parameters to control a remixing of the mono signal, along with a de-correlated version that adds width or spaciousness, back into stereo. This is done in five to forty frequency bands, depending on the bitrate employed.

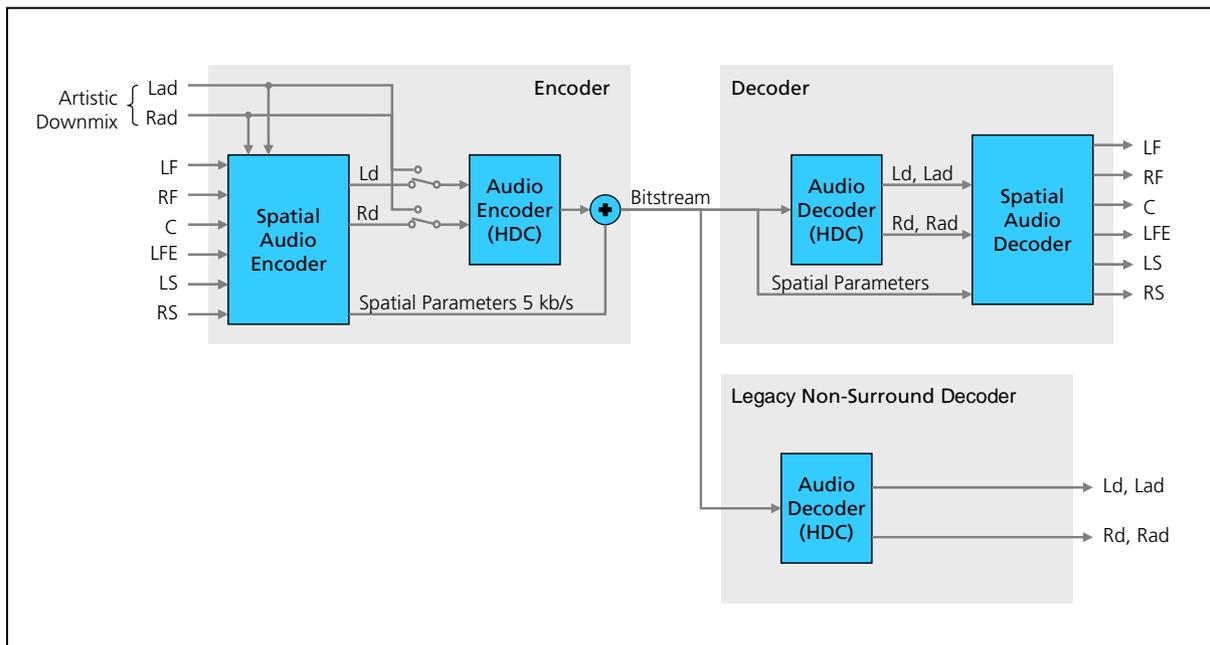


Figure 3. Applying Spatial Encoding to HD Radio. A stereo or mono mixdown is made and encoded with the standard HDC audio codec. The spatial parameters (about 5 kb/s) are added to the bitstream. In the decoder, the output of the HDC codec is up-mixed to recreate six channels using the transmitted spatial parameters. A legacy decoder just outputs the downmixed signal. Note that a separate artistic downmix can be used instead of the fixed one made in the spatial encoder.

Extending this concept to six channels for HD radio, in the encoder six channels are mixed down to stereo and the stereo signal is encoded with the standard HDC codec, as shown in Figure 3. Then the 5 kb/s of spatial parameters are added into the bitstream for transmission. In the decoder, the standard HDC codec

reconstructs the stereo signal, and then the spatial parameters are used to recreate the six channel signal. A legacy non-surround decoder just outputs the stereo signal. Note that a mono downmix could be used instead of stereo, if the bitrate needs to be halved for multicasting. Using the mono downmix results in lower, but highly acceptable surround quality, and the decoder can also produce a stereo output as well as a surround one from the mono signal.

An additional feature of MPEG Surround is the ability to use a separate artistic downmix instead of the fixed downmix produced in the encoder. This downmix, while offering the artist or producer complete control over the stereo or mono reproduction of the content, can still be used in the decoder to re-create the original surround mix.

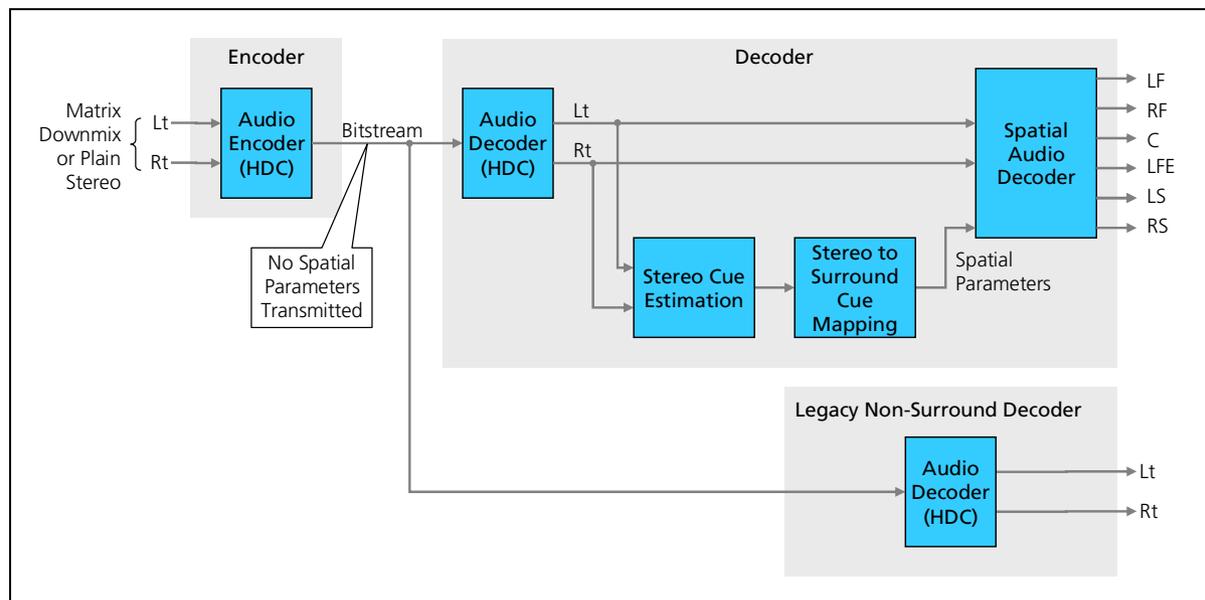


Figure 4. Using MPEG Surround's Independent Mode to Decode Matrix or Analog Blend Content.

For HD Radio, broadcasters must consider that some items in their playlist may not be available in surround, yet they would like to avoid collapsing the sound image to stereo when they are played. There is also the case where a fringe listener may lose the digital signal and blend to analog reception.

For these cases, MPEG Surround offers an independent mode (termed "non-guided mode" in the standards documents). The technologies normally used in the encoder to extract the sound image parameters can be used in an independent decoder to recover spatial cues just from an input stereo signal. In this mode, spatial reproduction is not as good as having the spatial parameters transmitted for surround content, but on content that is only available in stereo or matrix encoding, MPEG listening tests show it produces better spatial quality than existing Pro Logic II decoders.

5 Application to HD Radio

As shown in Table 1, MPEG Surround offers the flexibility to be used in almost any operational configuration for HD radio. In addition to approaching perceptually discrete surround quality on a full 96 kb/s channel signal, MPEG Surround can also be used with very good quality at 64 kb/s for multicasting. MPEG Surround offers two options for two-program multicasting: a 48 kb/s channel can be encoded as stereo audio so that existing HD Radio receivers will reproduce it in stereo, or encoded as mono audio for better downmix audio quality.

The latter case is particularly interesting since a non-surround HD radio (perhaps a kitchen or table radio) would reproduce a higher-quality audio program in this mode, just without stereo. An MPEG Surround equipped radio (such as a car radio or home A/V receiver) would reproduce full surround or stereo, with less audio coding artifacts than would be present if a stereo signal was transmitted.

Given that MPEG Surround can use a mono audio channel, it is also possible to use lower bitrates for secondary programs. If a 64 kb/s channel is used for a main program, this allows a secondary channel to be encoded in mono at 27 kb/s, which will provide significantly higher quality compared to stereo encoding at this bitrate. For reduced bandwidth applications, perhaps for news or talk formats, a 16 kb/s channel could be used, with MPEG Surround providing a surround effect useful for panel discussions, actualities, or drama.

Application	Spatial Bitrate	HDC Audio Signal	Audio Bitrate	Spatial Quality	Core Audio Quality	Application
Full Channel – 96 kb/s	16 kb/s	Stereo	80 kb/s	Excellent	Very Good	All
Quality Multicast – 64 kb/s	5 kb/s	Stereo	59 kb/s	Very Good	Good	All
Half Channel – 48 kb/s	5 kb/s	Mono	43 Kb/s	Very Good	Very Good	2 nd Music Ch.
Half Channel Stereo – 48 kb/s	5 kb/s	Stereo	43 Kb/s	Very Good	Fair/Good	Simulcast ½ Channel
Secondary Channel – 32 kb/s	5 kb/s	Mono	27 Kb/s	Very Good	Fair/Good	2 nd Music Ch.
Special Purpose – 16 kb/s	3 kb/s	Mono	13 Kb/s	Fair	Limited	News/Talk

Table 1. Suggested Operational Parameters for MPEG Surround on HD Radio

6 Advantages and Disadvantages of MPEG Surround

MPEG Surround offers many advantages when used for HD Radio broadcasting:

- Stable, precise surround image with accurate reproduction of surround content
- Ability to decode analog content during digital signal fades using Independent Mode
- Ability to decode matrix encoded content or synthesize surround from stereo content using Independent Mode
- Side channel data rate may be adjusted by the broadcaster to meet his own requirements for surround image accuracy
- Operation at low multicasting channel bitrates with improved audio quality using mono audio signal.
- An optional artistic downmix, or if desired, matrix encoding for analog surround, may be used instead of the fixed downmix
- Matrix encoding present in the downmix is completely removed or “inverted” in the MPEG Surround decoder so there are no matrix artifacts on the surround outputs.
- MPEG Surround is an open international standard, and implementations will be available from multiple technology suppliers, just as for the MP3 and AAC codecs

MPEG Surround also has several disadvantages relative to traditional surround techniques:

- MPEG Surround will only decode analog content in Independent Mode, which is somewhat better than traditional matrix decoders, but requires the downmix content to be matrix encoded for best performance.
- MPEG Surround is new technology which has just been standardized, and will require time to be integrated into production and transmission equipment and decoder chips.

- MPEG Surround will require content to be stored in discrete multichannel form, if voiceovers and segues are to be done on the air.

7 Suggestions for Broadcaster Testing of Surround Systems

7.1 Conducting a Listening Test

Since the perceived quality of audio codecs is subjective, listening tests must be carefully arranged to eliminate emotional and sequence biases of the listeners and their hearing or perceptual limitations. It is possible to conduct a valid informal listening test in a broadcast facility with only a small investment in time and materials, if the many subtle and non-obvious pitfalls of testing are avoided. A good reference for understanding how to conduct a listening test is *RECOMMENDATION ITU-R BS.1534-1, Method for the subjective assessment of intermediate quality level of coding systems*, available for [free](#) from the International Telecommunications Union <http://www.itu.int/publications> web site.

It is important to realize that casual listening while switching between two systems is not testing, it is listening training. A/B listening, particularly on difficult content, is a useful way to learn how to hear artifacts of surround systems. This can be used to gain an initial impression of what to listen for, but should be followed by a listening test according to the above guidelines.

Listening tests are not usually corrupted by minor deficiencies in equipment or environment, but by decisions on how the tests are conducted. For example, common errors include:

- Not using the original content as a reference in the tests
- Not using the same content to test each system or configuration
- Differences in reproduced level between systems under test
- Not using a hidden reference signal, or not excluding listeners who cannot hear it
- Comparing systems that were tested in different tests
- Allowing listeners to know the origin or identity of a signal

All of these errors are prevented by the BS.1534 methodology. Efficiently conducting tests usually requires the use of software to control the presentation of test items and collect the test results. Professional tests generally use software such as CRC [SEAO](#) or Audio Research Labs [STEP](#). The free program [ABC/HR](#) can be configured to perform these tests, but it does not currently support multichannel content.

The results of the tests can be easily analyzed using Microsoft Excel to create the traditional graph with mean rankings and error bars for each test condition. A procedure for doing this is provided in the [STEP manual](#).

The time required to study specifications and prepare a valid test is usually small relative to the listening time of the participants. In many cases, the results of such tests are surprising to those who have done casual, biased listening.

7.2 Test Content

Undoubtedly broadcasters will want to consider test content from their genre or playlists that reflect typical program material. However, it is also useful to include difficult or pathological test material that will stress the system under test and more clearly reveal artifacts. In the case of MPEG Surround, one set of difficult content involves distinct, localized sounds in the presence of wideband, diffuse noise, such as applause. An example of this content is the MPEG Applause or ARL Applause sequences. In the case of matrix systems, some content may noticeably altered by the phase shifts introduced during encoding. One example of this is the vocal track of "You took the words right out of my mouth", on the Meatloaf "Bat Out of Hell" CD.

8 References

1. International Organization For Standardization, ISO/IEC JTC 1/SC29/WG11, Coding Of Moving Pictures And Audio. "Tutorial on MPEG Surround Audio Coding", Document MPEG2005/N7390, July 2005, Poznan, Poland. <http://www.chiariglione.org/mpeg/technologies/mpd-mps/index.htm>
2. International Organization For Standardization, ISO/IEC JTC 1/SC29/WG11, Coding Of Moving Pictures And Audio. Document N7138, "Report on MPEG Surround Coding RM0 Listening Tests", Busan, Korea, 2005. http://www.chiariglione.org/mpeg/working_documents/mpeg-d/sac/RM0-listening-tests.zip
3. International Organization For Standardization, ISO/IEC JTC 1/SC29, Coding of Audio, Picture, Multimedia and Hypermedia Information. "ISO/IEC FCD 23003-1, Information technology — MPEG audio technologies — Part 1: MPEG Surround", Document N7947, Bangkok, Thailand, January 2006.
4. Lars Villemoes, Jürgen Herre (FhG-IIS), Jeroen Breebaart, Gerard Hotho, Sascha Disch (FhG-IIS), Heiko Purnhagen, Kristofer Kjörling. "Mpeg Surround: The Forthcoming ISO Standard For Spatial Audio Coding", presented at the Audio Engineering Society 28th International Conference, Piteå, Sweden, June 30-July 2, 2006.
5. Jeroen Breebaart, Jürgen Herre (FhG-IIS), Christof Faller, Jonas Rödén, Francois Myburg, Sascha Disch (FhG-IIS), Heiko Purnhagen, Gerard Hotho, Matthias Neusinger (FhG-IIS), Kristofer Kjörling, Werner Oomen. "MPEG Spatial Audio Coding / MPEG Surround: Overview and Current Status", presented at the 119th Convention of the Audio Engineering Society, October 7-10, 2005, New York, NY. Preprint number 6599. www.aes.org.
6. Jürgen Herre (FhG-IIS), Heiko Purnhagen, Jeroen Breebaart, Christof Faller, Sascha Disch (FhG-IIS), Kristofer Kjörling, Erik Schuijers, Johannes Hilpert (FhG-IIS), Francois Myburg. "The Reference Model Architecture for MPEG Spatial Audio Coding", presented at the 118th Convention of the Audio Engineering Society, May 28-31, 2005, Barcelona, Spain. Preprint number 6447. www.aes.org.
7. International Telecommunications Union. "RECOMMENDATION ITU-R BS.1116-1, Methods For The Subjective Assessment Of Small Impairments In Audio Systems Including Multichannel Sound Systems."
8. International Telecommunications Union. "RECOMMENDATION ITU-R BS.1534-1, Method For The Subjective Assessment Of Intermediate Quality Level Of Coding Systems."
9. Gerhard Stoll and Franc Kozamernik. "EBU listening tests on Internet audio codecs." European Broadcasting Union Technical Review, June 2000.

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Annex 3 – Neural Surround

Report submitted by Neural Audio



Neural Surround™ Backgrounder

Neural Surround™, a breakthrough in audio technology, was developed by Neural Audio in cooperation with leading electronics manufacturers to bring the excitement of surround music to a new listening audience.

Neural Surround capable receivers launched in the US market in spring of '06. With the support of leading broadcasters such as XM Satellite Radio and others – US consumers now can enjoy surround music via analog and digital radio broadcast.



Neural Surround provides the rich envelopment and discrete image detail of surround sound in a format 100% compatible with stereo. With superior spectral resolution and channel separation, Neural Surround™ draws the brain's attention to sonic details in musical instruments, vocals, and ambience that are typically masked by other playback systems. This allows the listener to fully experience the richness and subtleties in recorded performance as never before.

Neural Surround™ is being adopted by leading consumer electronic brands. By the fall of 2006, more than 60% of all surround home receivers in the United States will offer Neural Surround™ technology.

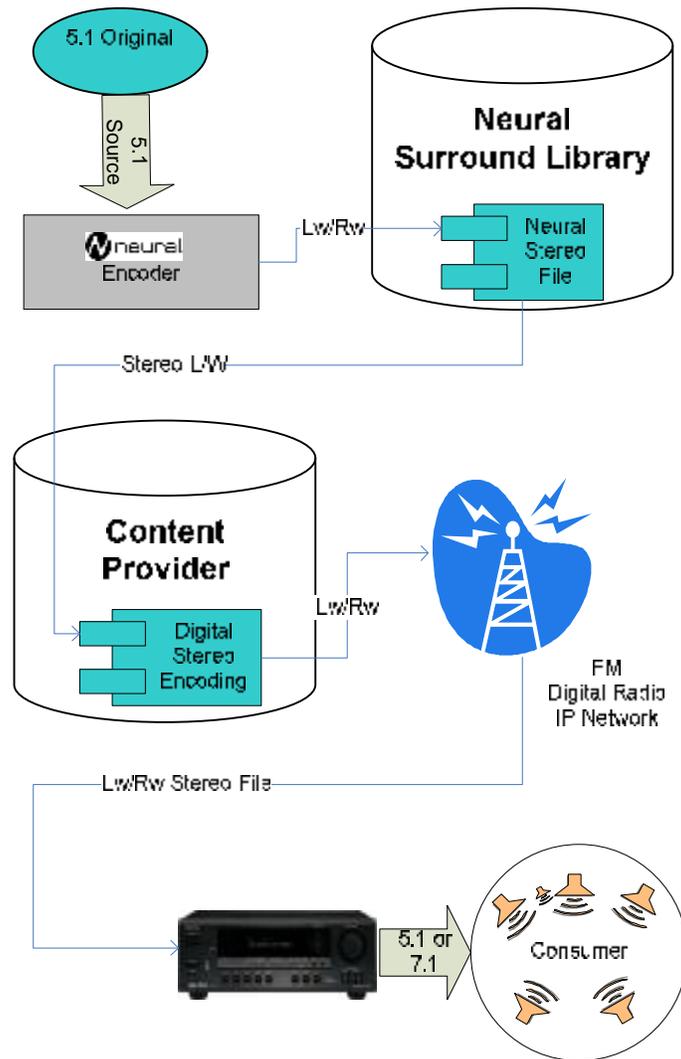
In addition to the record pace adoption in the US, a launch in European and Asian markets is planned for spring 2007.

In addition to satellite and terrestrial radio, the Neural Surround™ technology is widely used to solve stereo-to-surround audio compatibility issues by television networks such as ABC, NBC, Fox and CBS.

For more information; www.neuralsurround.com or www.neuralaudio.com .

How does Neural Surround broadcast work?

The Neural Surround™ process encodes surround material by “watermarking” the surround spatial cues on a downmixed stereo signal described as “Lw/Rw”. This simplifies the distribution of and consumer access to surround material. The Neural Lw/Rw signal can be efficiently managed within any stereo broadcast plant and audio distribution path.



On the consumer side, any listener who owns mono, stereo or matrix-style receivers can enjoy the Neural Surround broadcasts as mono or stereo. But when a Neural Surround™-equipped receiver is added, the watermarked spatial cues encoded in the Lw/Rw signal are recovered and a full Neural Surround™ experience is delivered.

Annex 4 – SRS Circle Surround

Report submitted by SRS Labs



CIRCLE SURROUND APPLICATION GUIDE



SRS Labs Headquarters
2909 Daimler Street
Santa Ana, CA 92705

Tel: 949-442-1070
Tel: 800-243-2733
Fax: 949-852-1099

SRS 
www.srslabs.com



Accuphase



HITACHI



aiwa



LOEWE



DENON



HUGHES



marantz



BenQ

e.Digital



Intel

KENWOOD

M-AUDIO

DELIVERING ADVANCED AUDIO SOLUTIONS TO THE WORLD

SRS Labs is one of the world's leading technology companies with a vast portfolio of audio, voice, surround sound and semiconductor solutions. The company works with the top manufacturers of consumer electronics products, who look to us to provide a richer entertainment experience through patented sound techniques and quality semiconductor solutions. To date, SRS audio solutions have been included in over 600 million products from the world's leading brand names in five key consumer electronics market segments: home entertainment, portable media devices, personal telecommunications, automotive and personal computer.

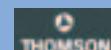
The Company's audio solutions are also used by the broadcast, post-production, music, cinema and radio communities to deliver surround sound and enhance the quality of live and pre-recorded audio and video material.

Fact:

Anywhere stereo can go, Circle Surround can go.

Did you know...

that Circle Surround can be compressed down to 48kbps?



WHY SURROUND SOUND?

Surround sound puts the listener in the middle of the performance, creating an immersive and thrilling experience.

WHY SRS CIRCLE SURROUND?

SRS Circle Surround ("CS") is an advanced surround format that delivers full multichannel audio to the home, car or cinema. The advanced Circle Surround system encodes up to 6.1-channels of audio for transmission over standard stereo two-channel carriers and maintains highly accurate steering and channel separation during decoding. Circle Surround-encoded material is 100% compatible with other consumer surround decoders and can be played back in both mono and stereo systems without decoding. Circle Surround preserves the creative intent of the original mix, and brings the engineers and producers hard work to life.

WHY SRS CIRCLE SURROUND FOR HD RADIO™?

SRS Circle Surround surpasses the limitations of other surround systems by offering easy to use hardware and software encoding solutions and fully customizable decoding solutions for the car, home, and portable and mobile players.

Our encoding solutions integrate seamlessly into the HD Radio™ broadcast and playout infrastructure. With encoding products available for the leading digital production platforms such as TDM and VST as well as rack mount AES/EBU hardware products, delivering Circle Surround content for HD Radio has never been easier. Moreover, unlike other proposed surround formats, Circle Surround requires the use of no additional bandwidth to deliver superior sonic fidelity.

Circle Surround decoders can be found in millions of consumer products from Yamaha, Kenwood, Panasonic, JVC, Toyota, Visteon, Fujitsu-Ten, and many others. It is also the industry's only multichannel decoding solution featuring two patented SRS post processing technologies; Dialog Clarity™ and TruBass®. Finally, SRS Circle Surround can be found along side HD Radio in more consumer products than all of the other formats combined.

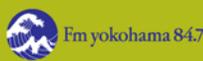
It is the most flexible, compatible and accessible surround sound format available today.

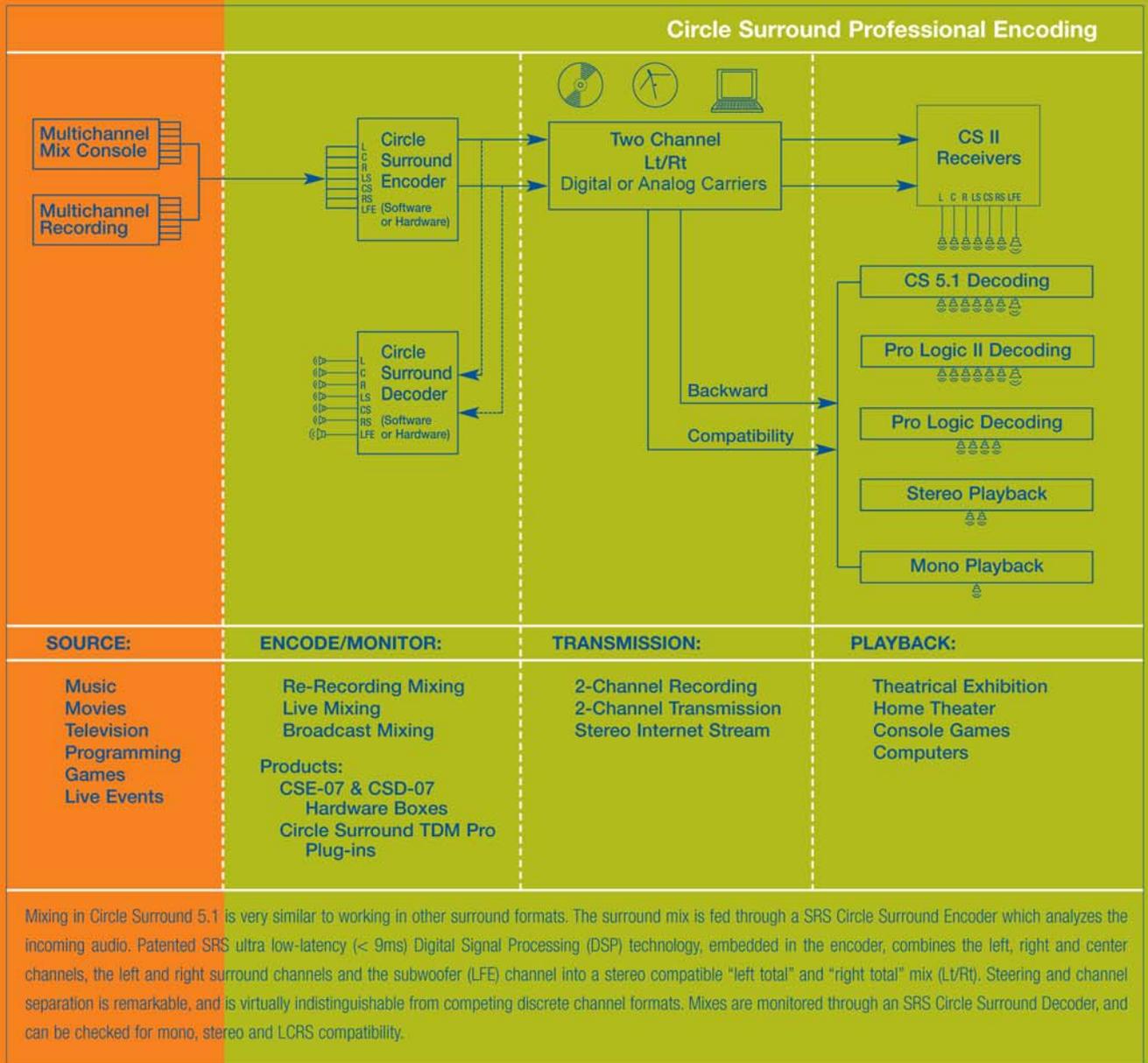
Fact:

Circle Surround is a digital signal processing technology, not a compression technology.

Did you know...

an iPod, or other MP3 players, can store and deliver Circle Surround content?





"Now that we have taken the XGames to a completely live format, there is no way that we would ever be able to provide a surround delivery if it wasn't for the tools that Circle Surround offered us."

Ron Scalise - ESPN



Live Broadcast

Circle Surround delivers 5.1-surround sound in an Lt/Rt two-channel playback format. This means live television and radio can be delivered for playback and broadcast in 5.1-surround over existing stereo infrastructures. The Circle Surround-encoding process allows for the transmission and delivery of 5.1-encoded programming through virtually any broadcast chain.

SURROUND SOUND FOR TELEVISION

For live television programming, Circle Surround not only enables the transmission of a 5.1-encoded mix over a standard definition (“SD”) stereo broadcast, it also provides mono, stereo, four-channel LCRS (Left, Center, Right, Surround) and 5.1-surround compatibility in a single delivery standard with no delay introduced. Circle Surround-encoded material passes straight through existing stereo infrastructures without requiring a change in equipment. For broadcasters currently mixing in surround for high definition (“HD”) delivery, Circle Surround can be used on the SD feed, enabling 100% of audiences with home theater systems to enjoy surround sound.

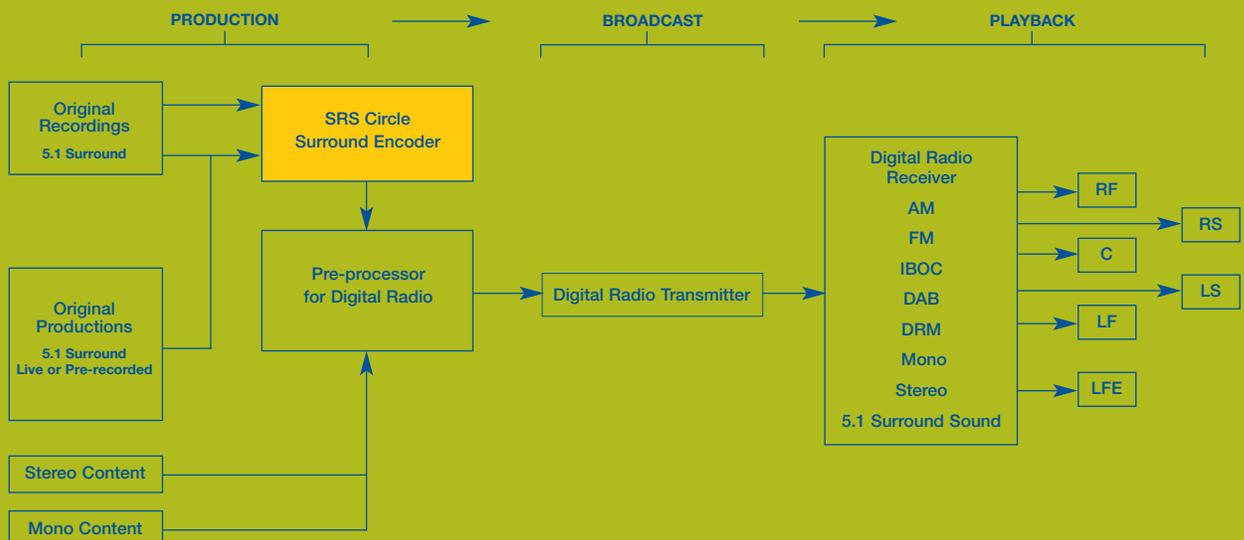
SURROUND SOUND FOR DIGITAL RADIO

The unique features of Circle Surround make it the ideal surround format for the new trend in digital radio broadcasting and a true value-add for broadcasters. Not only is it “format agnostic” and works with any audio standard — IBOC, DAB, ISDB-T — but it can be compressed to as low as 64kbps while still preserving the surround information. Additionally, Circle Surround is transparent on all analog broadcasts, requires no additional bandwidth or storage and is easy to implement in the broadcast and production chain.

Fact:
Circle Surround is compatible with every playback system.

Did you know...
Circle Surround decoders can be found in home theaters, movie theaters, automobiles, and computers?

DIGITAL RADIO FLOW



Music

WHY SURROUND MUSIC

Delivering music CDs in surround sound is a concept that has widespread appeal, but consumers have been hesitant to adopt a new format or type of hardware. Circle Surround solves this challenge and delivers a 5.1 surround sound mix over the stereo tracks of a standard Redbook compact disc. Now one CD with one mix can satisfy all music lovers.

A unique advantage to mixing Circle Surround-encoded CDs is they can be enjoyed in full surround when routed through any home theater or automotive receiver equipped with a decoder, yet the CDs are also 100% stereo compatible and will play back on any stereo system. Circle Surround CDs are “radio ready” for broadcast in stereo, and playback in mono, stereo or surround. Other discrete surround formats such as SACD, DVD-Audio and DTS CDs are not stereo compatible and will only playback through their respective decoders.

Circle Surround CDs do not require separate packaging or retail shelf space. Since the surround mix is encoded in the stereo tracks, there is one product and no need for two separate releases. This advantage provides significant cost savings for record labels.

Circle Surround faithfully reproduces the original surround mix with stunning accuracy. Vocals are crisp and clear, bass is robust, and instruments are sharp and vivid. The primary benefit of listening to a CD mixed in Circle Surround is knowing that you’re hearing what the artist, engineers and producers intended for you to hear.



“I think every compact disc should be produced in Circle Surround.”

James “Jimbo” Barton – Music Engineer: Rush, Matchbox Twenty

Circle Surround FAQ's

WHY ENCODE IN CIRCLE SURROUND?

Encoding in Circle Surround preserves the *creative intent* of surround mixes. Whether it is a television series, live-sports broadcast, music CD or a concert DVD, audiences will experience what the artists, engineers and producers intend for them to hear.

WHAT IS A 5.1 LT/RT?

Lt/Rt stands for *Left total/Right total*. It is the sum of matrix surround information encoded in the Left and Right channels. Many industry professionals do not realize that an Lt/Rt is no longer limited to 4-channels. SRS Labs has developed an advanced matrix encoding technology that can encode 5.1 or 6.1 discrete channels into an Lt/Rt. Circle Surround is the only 6.1 (optional center surround) matrix encoding process available. Circle Surround will playback in stereo when no surround decoder is present, or in LCRS, 5.1 or 6.1 surround when decoded. In addition, the Circle Surround Lt/Rt is cross compatible with other surround playback systems.

IS CIRCLE SURROUND ANALOG OR DIGITAL?

Circle Surround is actually neither. It uses patented Digital Signal Processing (DSP) technology to encode and decode material from both analog and digital sources. SRS Labs manufactures analog and digital (AES/EBU) hardware encoders and decoders, as well as TDM and VST software plug-ins for content creation.

DOES CIRCLE SURROUND USE COMPRESSION?

Circle Surround *does not* use compression during encoding, and amazingly only uses the equivalent of two channels of data or bandwidth for storage and transmission. It has a distinct advantage in live broadcast because it does not introduce delay or latency, and stays in sync with picture. Circle Surround can actually be compressed after encoding for more efficient delivery or streaming. Tests have shown that surround playback integrity holds up to compression as low as 64MBbs.

WHAT IS THE ADVANTAGE OF CIRCLE SURROUND VERSUS DISCRETE SURROUND?

Circle Surround 5.1 encoded programs and material can be broadcast over the current radio and television broadcast infrastructure without any modifications or changes. Consumers who have home theater or automotive receivers with a surround decoder can enjoy surround mixes as they are intended to be heard. Circle Surround can be used for encoding 5.1 Compact Discs, on supplementary DVD audio channels, in post-production and in live broadcast.

Fact:

The existing two-channel infrastructure of most broadcasting companies cannot support discrete multichannel surround sound formats.

Did you know...

that Uncle Kracker's hit record, *72 and Sunny* was released in Circle Surround 5.1 on a standard Redbook compact disc?



"Quality on the backend is phenomenal for the end-user."

Brian Slack - Widget Post

**Annex 5 – An overview of the causes of distortion in FM signal
reception**

Report submitted by Dolby Laboratories

An overview of the causes of distortion in FM signal reception.

One of the shortcomings of FM transmission is its susceptibility to multipath distortion caused by the delay between the reception of the main signal arriving directly from the transmitter and one or more copies of that signal that arrive at the receiver later than the main signal because they are reflected by terrain or buildings and have to traverse longer paths.

A slightly different form of the above FM Stereo system called FMX was proposed in the late 1980s. Bose and Short¹ wrote a paper that analyzed the performance of the FMX system in the presence of multipath signal conditions. The principles they develop can be applied to the existing FM system, so can be used to examine the influence of matrix encoded audio signals on FM reception.

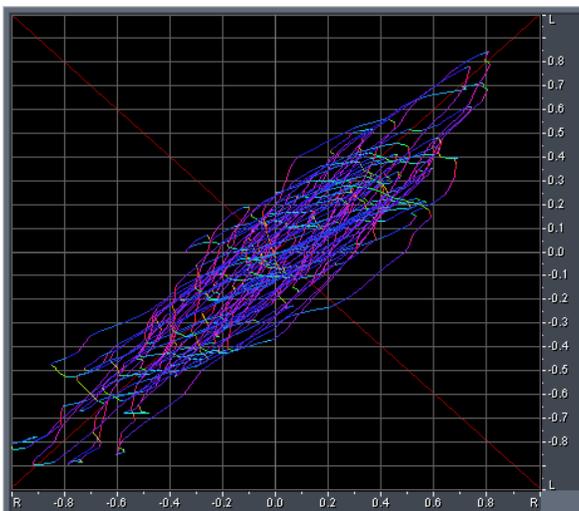
Section 4.4 of the paper reviews the factors affecting multipath, based on the mathematical models developed earlier. It says:

“Equation 19 shows us directly which factors are most significant for determining the amount of error voltage created by multipath. All other things being equal, higher levels of modulation create higher levels of multipath signal distortions and noise. And, because of the time derivative in equation 19 higher frequency modulation creates more multipath distortion and noise. Therefore, the 38 kHz S [stereo subcarrier] signal contributes considerably more to the multipath problem than does the M [the mono or L+R] signal. This is why mono broadcasts have very much reduced multipath problems compared to stereo. Additionally, SCA and other services with their high frequency subcarriers make the effects of multipath worse. Finally, longer path length differences between direct and reflected paths, with all other conditions held constant, make multipath effects worse.”

Bose and Short explain the role of the time derivative in Section 3.1. “...the instantaneous frequency error at the output of the receiver detector is directly proportional to the derivative of the modulation”. For our purposes, and in the absence of any signals in the 53 to 99 kHz region, the value of the time derivative is proportional to the level and frequency of the stereo subcarrier components. Since the surround signal is carried as part of the stereo subcarrier, and thus affects the overall level of the (L-R) signal modulating the subcarrier, it can influence the susceptibility of the FM signal to multipath interference. To get an idea of how significant this effect is, we have to look at the differences between the (L-R) components of typical stereo (Lo Ro) and matrix encoded (Lt Rt) signals.

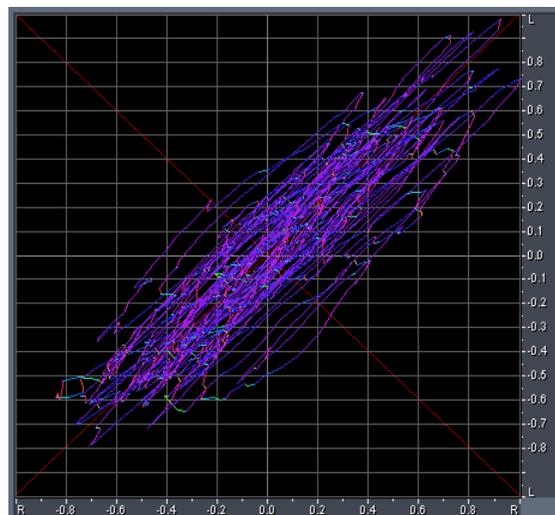
The (L-R) signal falls on the upper left to lower right axis of an X-Y or phase display. All the screen shots represent about 0.1 second of the program signal.

¹ A Theoretical and Experimental Study of Noise and Distortion in the Reception of FM Signals. Amar Bose and Wm. Short, copyright MIT, Cambridge MA, 1989, also reprinted as a “Classic Paper” in IEEE Transactions on Broadcasting, Volume 47 No. 2, June 2001

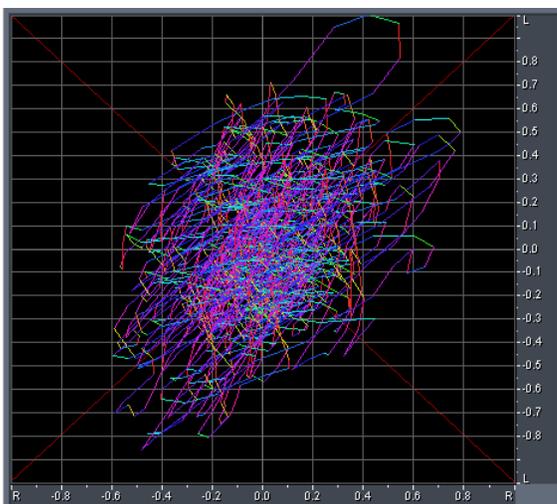


Claude Bolling, California Suite, Track 1, "California" at 1:22.6 on CBS MK 36691

This is a typical Artistic Stereo signal. It is pretty "center heavy" with most of the energy in the in phase (L+R) direction with some panned sources or reverb contributing to the (L-R) or out of phase component.

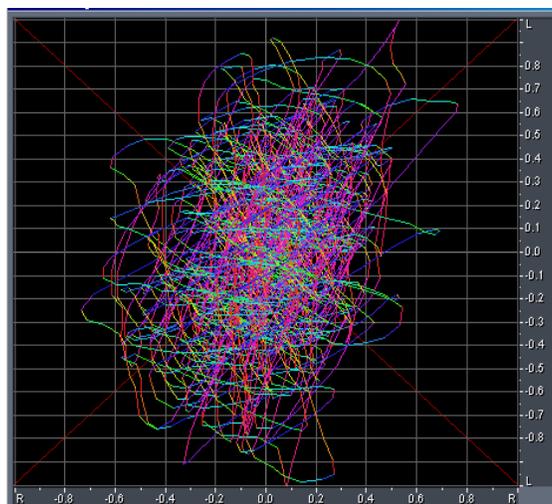


This is a Pro Logic II encoded (Lt Rt) downmix of a 5.1 channel film soundtrack, taken from track 4 of the Dolby Pro Logic II demo CD. The scene is a large crowd gathered around a group of heretics being burned at a stake in the middle of a square. The crowd noise is all around, but one of the heretics' cries in the center channel dominates the auditory scene. It can be taken as an example of a good surround mix with emphasis on the Center channel. Note, the Pro Logic II examples are taken from this test disc because no commercial movie or music discs use Pro Logic II encoding.

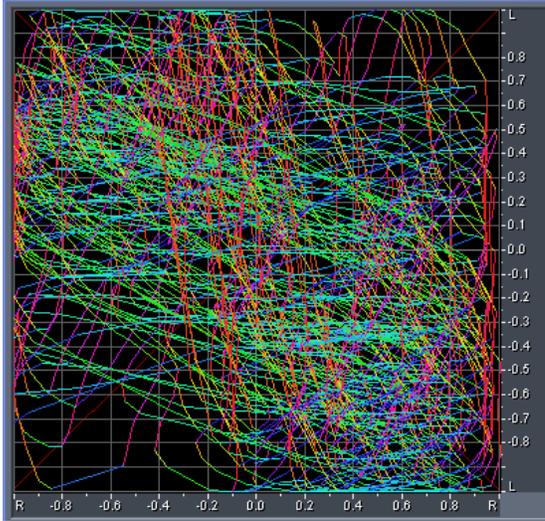


Artistic Stereo from Track 10 at 1:06.4 of
Dolby CD – ICES 2006 PC
Rock band with center male vocalist

Another artistic stereo signal, this time with more energy in the (L-R) component, due to a more complex mix of a rock band. This cut sounds quite “spatial” as a stereo signal, and if decoded, provides quite a pleasing surround presentation.

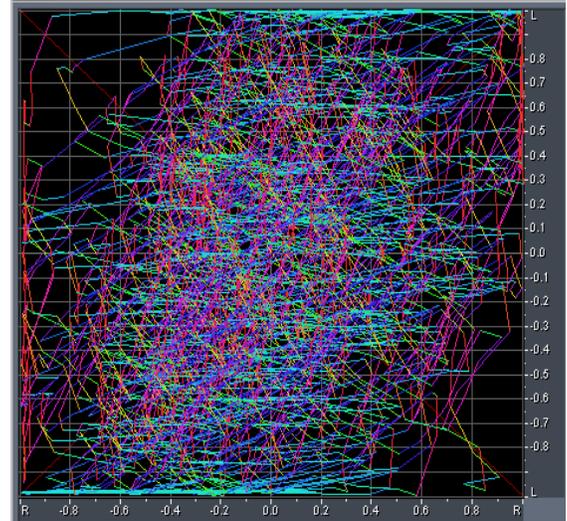


This is another section of the Pro Logic II (Lt Rt) encoded downmix of a 5.1 channel film soundtrack, taken from track 4 of the Dolby Pro Logic II demo CD. This time there is no center dialog, but there is surrounding crowd noise with incidental voices from many directions, and a choir predominantly in the surrounds, at a higher level than the crowd noise. It can be taken as an example of a good surround mix with emphasis on the Surround channels.



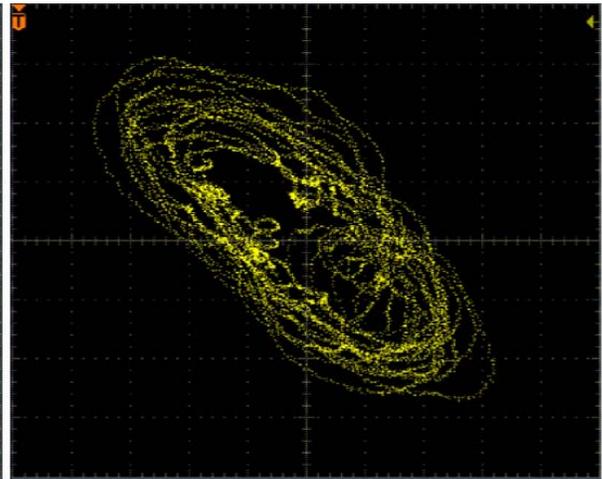
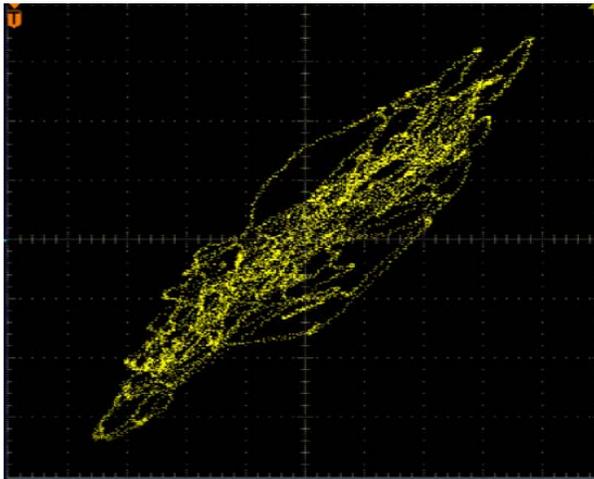
Christine Aguilera, Stripped, Track 1,
 “Stripped” at 1:23.5 on RCA
 B00006CXXU

This is an example of a highly processed (and clipped) Artistic Stereo signal, with roughly equal energy in the (L+R) and (L-R) channels.

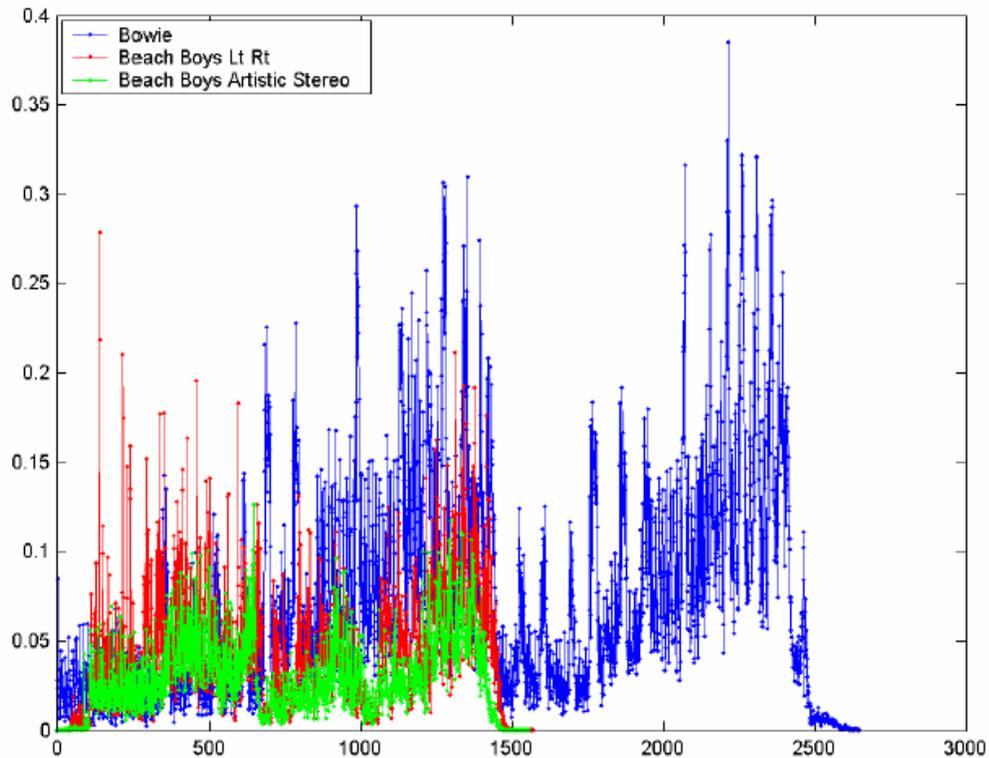


About 0.1 sec taken from the Artistic Stereo mix on the David Bowie, “Reality” disc, track 3, Never get Old, at approximately 3:41

Again, lots of energy in the both the (L+R) and (L-R) directions



This is a copy of the Beach Boys selection shown in part of Figure 6, in the body of the paper. The display of the artistic stereo signal is nearly identical to the Bolling artistic stereo signal display, while the downmix is dominated by the out of phase or (L-R) components. It is interesting to compare the (L-R) energy in the Artistic Stereo and Lt Rt downmix versions of the Wouldn't it be Nice tracks to that of the Bowie, Never get Old Artistic Stereo track.



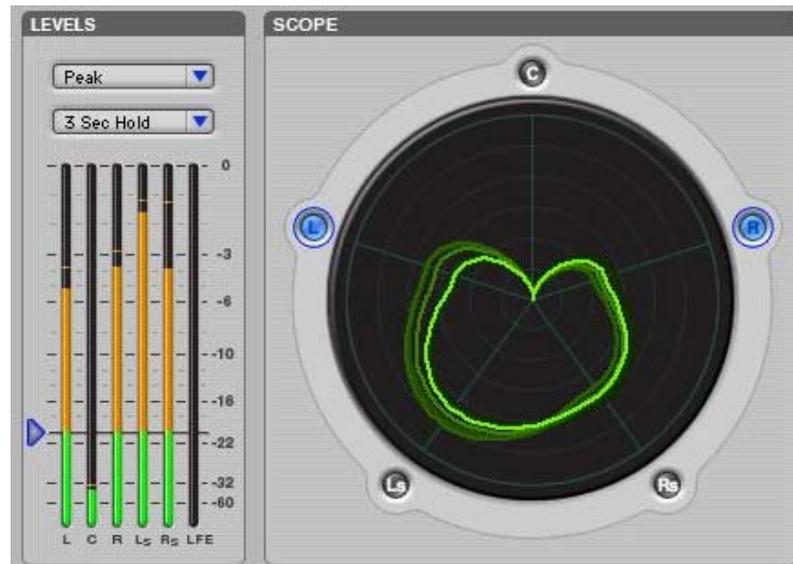
Each dot on the plots shows the mean squared level of a 0.1 second sample of the (L-R) component of the two channel signal. The highest peak (at about 2200 on the time axis) corresponds to the Bowie X-Y screen shot shown above, taken at 3:41. The inputs to the routine that generated the plots were either ripped directly from the discs, or taken directly from the digital Lt Rt output of the Pro Logic II encoder used to downmix the 5.1 channel version. (Note that this downmix may not be absolutely identical to the one used to produce the right hand X-Y plot of Figure 6, as it was done with a Neural encoder).

This diagram emphasizes the fact that the susceptibility of an FM signal to multipath distortion is determined by a number of factors (as pointed out by Bose and Short) including the receivers (see the NPR report) and not just by the amplitude of the (L-R) stereo subcarrier. If the subcarrier amplitude was the only culprit, then broadcasts of the artistic stereo mixes represented by the Bowie and Aguilera stereo material shown here would certainly have suffered enough distortion to prompt listener complaints. This has not happened on any large scale; in fact Japanese FM radio broadcasters have been broadcasting matrix encoded material for a number of years without complaints. As the other plots above illustrate, there is often a great deal of similarity between the X-Y plots of Artistic Stereo and matrix encoded material. The MTS Television stereo sound transmission also uses FM (albeit with noise reduction in the L-R channel); the majority of movies seen on TV have matrix encoded sound tracks, again without viewer complaints.

The “jellyfish” display is a useful tool for checking the relative channel levels of a multichannel mix to get an idea of how much surround information is present. Figure 7 in

section 6 of the paper shows a mix that has significant surround content, but which is balanced by the front signals in the left, center and right channels.

The display below of the multitrack mix of “Wouldn’t it be Nice” shows that the surrounds clearly dominate the mix. There are some L and R components, but the center channel is absent. This mix clearly has a completely different character than the artistic stereo mix.



[Nicholas D. Satullo](http://www.highfidelityreview.com/reviews/review.asp?reviewnumber=19059725) provided a very thorough analysis of the Pet Sounds DVD Audio disc when it was released in 2003 (read it all at <http://www.highfidelityreview.com/reviews/review.asp?reviewnumber=19059725>) in which he notes the very surround heavy character of the multichannel mix, and states that “the best way to enjoy this disc is by playing the two-channel high-resolution version through a surround processor that will convert it to multi-channel via either a Logic 7 or Dolby Pro Logic II matrix”.

The review points out the importance of checking the mono and stereo compatibility of the multichannel material delivered to or produced by a station that moves to Surround Sound operation. The mono compatibility of stereo material has been checked at the point of production for so long now that it is essentially unnecessary to check it again at the station. Multichannel music production is still relatively new, so it is important to do the compatibility checks, particularly when the X-Y or jellyfish displays are unusual.

As the art of making multichannel programs matures, there will (hopefully) be less and less need to check the downmixes, but for the present, it is important.

This section has only addressed what we may see or hear in the studio. The relative phase and amplitude of each channel can be affected by any audio processing gear placed between the studio and the transmitter. It is very important that the processing applied to each channel be coupled, so that the same thing is done to each channel. Even with that in place, the levels seen in the studio will not necessarily be the same as those applied to the transmitter.

NRSC-R207

NRSC Document Improvement Proposal

If in the review or use of this document a potential change appears needed for safety, health or technical reasons, please fill in the appropriate information below and email, mail or fax to:

National Radio Systems Committee
c/o Consumer Electronics Association
Technology & Standards Department
1919 S. Eads St.
Arlington, VA 22202
FAX: 703-907-4190
Email: standards@ce.org

DOCUMENT NO.	DOCUMENT TITLE:	
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URGENCY OF CHANGE: _____ Immediate _____ At next revision		
PROBLEM AREA (ATTACH ADDITIONAL SHEETS IF NECESSARY): a. Clause Number and/or Drawing: b. Recommended Changes: c. Reason/Rationale for Recommendation:		
ADDITIONAL REMARKS:		
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