Technical Notes Volume 3, Number 3:

JBL Professional Studio Monitors for Multichannel Sound Applications

1. Introduction:

Mixing for multichannel sound has become a very important aspect of audio postproduction. There are three driving forces: Video DVD, Audio DVD, and advanced digital TV. The introduction of the video DVD in 1996 has opened up many opportunities in smaller work environments, such as those normally used in video post activities. It is here where most of the films with multichannel digital soundtracks are being transferred into the DVD Video format. Later in 1998, specifications for the Audio DVD will be formalized, and that will open up another avenue for multichannel remix activities, both in the video post environment as well as in the traditional music recording environment. The prospect of digital TV, which will require a new terrestrial broadcasting infrastructure, will probably not get underway until the start of 2000.

Just as JBL Professional helped "write the book" for exhibition and dubbing theater loudspeaker technology, we propose now to do the same thing for Video and Audio DVD production for multichannel sound presentation. In this Technical Note, we will present a history of multichannel sound, leading up to current cinema formats. We will then examine the means that have been put forth for translating the cinema experience into the home environment, emphasizing JBL's important role in this area.

We will then cover listening and acoustical aspects of small to midsize production environments, underscoring the desired loudspeaker performance attributes and JBL's solutions, with recommendations for JBL Professional loudspeakers for various size installations. We will then discuss future directions in multichannel sound as they apply to the computer work environment. Finally, we will present a complete glossary of terms pertinent to multi-channel sound.

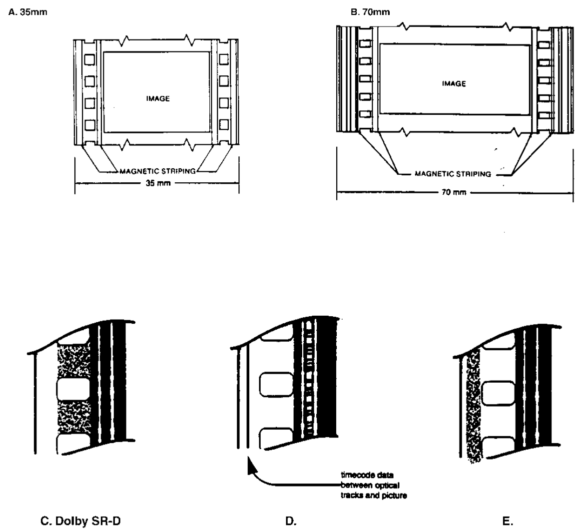
2. A Short History of Multichannel Sound:

The earliest studies in multichannel sound were carried out by Bell Telephone Laboratories during the early 1930's, when three-channel transmissions were made over long telephone lines connecting the Academy of Music in Philadelphia and Constitution Hall in Washington D. C. Much new technical ground was broken in these experiments, and the HF drivers used in JBL Professional's cinema products are in fact direct lineal descendants of those used in the Bell Labs experiments.

The first public demonstrations of multichannel sound were mounted by the Disney company for the soundtrack that accompanied "Fantasia," in 1939. This was of course a road show, and when its run was over, the sound developments that supported it were retired. A later road show, "Cinerama," was introduced in the early 1950's, and shortly thereafter the Cinemascope process was developed, along with a number of other anamorphic scoped 35-mm film formats for widescreen presentation. Later, the 70-mm format was introduced, supporting six magnetic channels on film, with five channels placed behind the screen along with a single surround channel (see Figure 1).

By the mid-fifties, the high fidelity industry had introduced two-channel stereo, and by 1957 the stereo disc was introduced. FM stereo was standardized in 1961, and the public was well on its way to an appreciation of spatial sound reproduction in the home as well as in the cinema.

Figure 1. **A summary of film formats for surround sound: 35-mm 4-track mag (a), 70-mm 6-track mag (b); Dolby Digital, with SR analog and AC-3 (c); DTS timecode track for maintaining sync with external CD-ROM (d); Sony SDDS (e).**



Surprisingly, there was little development in multichannel sound during the 1960's. But in the early 1970's, Dolby Laboratories, who had half a decade earlier made fundamental improvements in recording technology via their code-decode noise reduction system, turned their attentions to the problems of film sound, and a new round of development was underway. By standardizing loudspeaker playback equalization and levels in both the creative environment and the public exhibition environment, a new standard of film sound presentation rapidly evolved.

By the early 1980's, Dolby paved the way for significant economies in film production. Over the years, the costs of magnetic striped film had escalated to the point where 35- and 70-mm prints had become nearly prohibitive. Dolby's introduction of "Dolby Stereo" prints, a purely optical process, presented a stereo pair of tracks in which left, center, right, and surround program was encoded via a sum/difference phase matrix.

The matrix approach (based on the unsuccessful consumer "quadraphonic" movement of the early 1970's) provided limited channel separation in playback, but it was soon found that film sound mixers, if they monitored through the encode/decode portions of the matrix, could produce some quite convincing effects. The cost savings alone mandated that the film industry go ahead with the process, and eventually a vast "Home Theater" industry grew up around Laserdiscs and VHS tapes with their sound tracks encoded with Dolby Stereo.

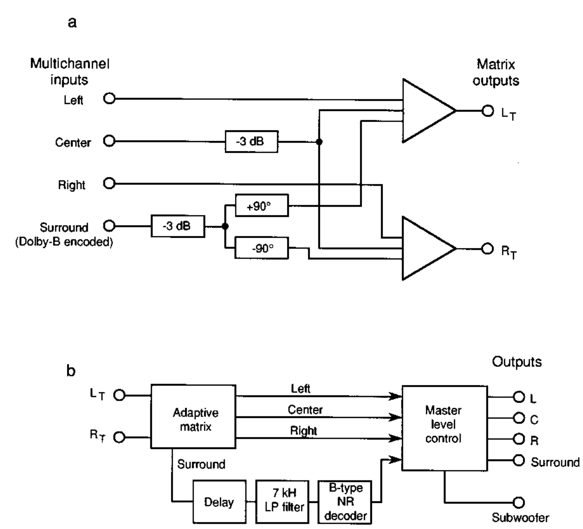
By the early 1980's, digital was beginning to make a presence in film sound. First was Optical Radiation Corporation (ORC) with their Cinema Digital Sound. Like many who are first to explore new technology, ORC paid the price with a number of costly engineering and marketing mistakes. They have been succeeded in recent years by Dolby (SR-D), Digital Theater Sound (DTS), and Sony Dynamic Digital Sound (SDDS), the major players of today in cinema digital sound.

While cinema installations worldwide number in the tens of thousands of screens, a far greater number of multichannel sound systems are to be found in the homes of consumers around the world who have invested in the so-called Home Theater market. This audience, which numbers in the millions of installations, is the target of today's international DVD initiative.

3. A Close Look at Today's Multichannel Formats:

Throughout the 1980's, Dolby Pro-Logic stereo was the mainstay of cinema surround sound. Figure 2 shows the basic working principles. Essentially, dialog is recorded as an in-polarity signal in both left and right channels. When this signal is detected, even momentarily, the matrix playback (demixing) coefficients are altered to favor the center playback channel. As a rule, dialog information and on-screen effects are treated in this fashion. Off-screen effects are recorded as anti-polarity signals; when this signal is detected the demixing coefficients favor the surround signal output, which is then fed to multiple loudspeakers placed on the side and rear walls of the theater. In order to enhance separation of the surround channel from the screen channels, the surround signal is delayed by up to 20 milliseconds in the rear of the house.

Figure 2. **Details of Pro-Logic. Encoding (a); decoding (b)**



The digital formats combine the foregoing presentation layout with discrete digital tracks, while providing a stereo pair for the surround channels. Basically, all three current digital film formats can be treated the same as regards signal integrity. They all work on some degree of perceptual (lossy) coding, in which psychoacoustical masking phenomena are used to reduce the digital bit rate. The basic operation is one of determining just what the instantaneous required bit rate actually has to be in order that the effects of masking (and unmasking) will be inaudible. For example, a loud, dense passage of music need not require the full 16- or 20-bit encoding process; it may turn out that only 4-bit coding will suffice because of the high degree of adjacent band-to-band noise masking potential. When this determination has been made by the system's internal "psychoacoustical" model, shorter word lengths can be invoked, along with their appropriate scale factors. Decode instructions are sent along with the data-reduced program, and a satisfactory reconstruction can then be made in the theater.

(Note: The Compact Disc does not work on these principles; it is an example of linear PCM, in which the program data transmission rate is fixed at 16 bits per channel with a sampling rate of 44.1 kS/s. The CD was on the drawing board nearly two decades ago when data reduction techniques were purely experimental.)

The audibility of data reduction is a favorite topic among engineers and audiophiles. It is true that most data reduction transmission systems can be made to "fail" (i. e., to be audible in the form of some reproduced signal artifact) with carefully chosen, or even arbitrary, input signal conditions. But the usefulness of these systems stems from the simple fact that in the cinema their operation is foolproof virtually all the time.

Dolby SR-D:

SR-D stands for Spectral Recording Digital. The digital signal is recorded at a fixed bit rate of 384 kilobits per second, and that data is placed in the unused space between sprocket holes on one edge of the film. The standard analog sound track space can then carry a Dolby stereo pair of optical tracks encoded with Dolby's Spectral Recording process (an analog noise reduction system), hence the name SR-D. In the Dolby digital process, should there be a failure, momentary or long-term, the system will switch over to the analog sound tracks, and the show goes on as usual.

SR-D supports 5.1 channels, that is, five full bandwidth channels for left, center, and right screen channels, a stereo pair of surround channels, and a special effects (below 150 Hz) track. The digital portion of SR.D is known as AC-3.

DTS:

The DTS process has its digital data recorded on CD-ROMs, which are played through a ROM drive governed by a sync track located on the film. The audio data rate is variable, depending on the demands of the program. The film also carries a stereo optical pair of tracks, so any failure of the digital portion of the system will result in a switch-over to analog. DTS is also a 5.1 channel system.

SDDS:

SDDS supports a total of eight full bandwidth channels. Five of these are normally assigned to the screen channel group (although relatively few theaters outside of the professional houses are equipped to do this). The remaining channels are then used for surround and special effects. The digital data is written on both edges of the film, which also carries a stereo pair of optical tracks. The is a provision in the system's front-end to allow five screen channels to be down-mixed to three channels for performance in commercial theaters that have not been outfitted with left-extra and right-extra screen channels.

Omnibus Prints:

Since the three digital systems use different sections of film real estate, it is possible to produce a film print that contains them all: Dolby between the sprocket holes, SDDS on the edges, the DTS time code track, and the standard analog stereo optical pair.

4. Multichannel Systems for Video Purposes:

Of the systems listed here, only Dolby AC-3 and DTS have application on DVD product. Dolby is the de facto standard for NTSC based video product, but DTS is an option for the producer of the disc as well.

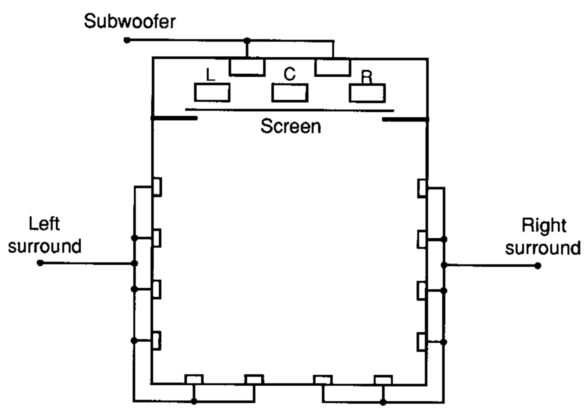
Systems for Music Only:

At the present time, standards for the Audio DVD are still in the process of being formed, and a final set of recommendations are due in mid-1998. However, a number of non-standard CDs have been made that are encoded with DTS 5.1 surround. These require a special DTS decoder which is connected to the digital output of a standard CD player. The output of that decoder is a 5.1 set of analog channels. A small number of Video DVDs have been made which contain 5-channel surround music only segments (e. g., music without moving picture.)

5. Bringing the Cinema Experience into the Home and Small Workspaces:

Figure 3 shows a typical 5.1 channel setup in a cinema. Note that there are a number of surround loudspeakers arrayed side and back of the patrons. The actual number of surrounds depends on the size of the house and the maximum sound levels that are desired in the listening space. In any event, there must be enough surround loudspeakers to provide what has been called "a significant number of insignificant sound sources." What this means is that any listener in the house should not be able to localize a sound source at any one loudspeaker, but rather be immersed in a thoroughly diffuse soundfield. Expectations in the cinema are that each surround channel be capable of matching the acoustical output capability of a single screen channel, and this usually requires up to 12 high sensitivity surround loudspeakers for each surround channel, adding to a total of 24 for the stereo pair of surround channels.

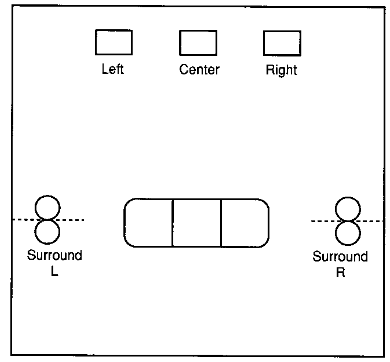
Figure 3. **Typical loudspeaker in a cinema.**



When the home theater market first got underway, it was quickly determined that the typical living room or den could not possibly handle multiple surround loudspeakers, and the problem of creating a diffuse field in the home was not to be solved for some time. Many feel that it still has not yet been solved, but an excellent step in the right direction is afforded by the dipole surround loudspeaker.

The dipole can be approximated by an unbaffled loudspeaker or by back to back loudspeakers in an enclosure connected in opposite polarity. These are both shown in Figure 4. Note that the output of the dipole is minimal along its ±90° bearing angles. If a pair of these loudspeakers are placed on the side walls of the listening room with their 90° "null planes" facing toward the primary listening area, a fair approximation of a diffuse field can be made. Under this condition, the majority of the sound from the dipoles that reaches the listener has undergone a reflection from the front or back of the listening space, and localization of the dipoles becomes ambiguous. This of course is desirable and in an important part of the approximation of the cinema experience.

Figure 4. **Dipoles in the listening space.**



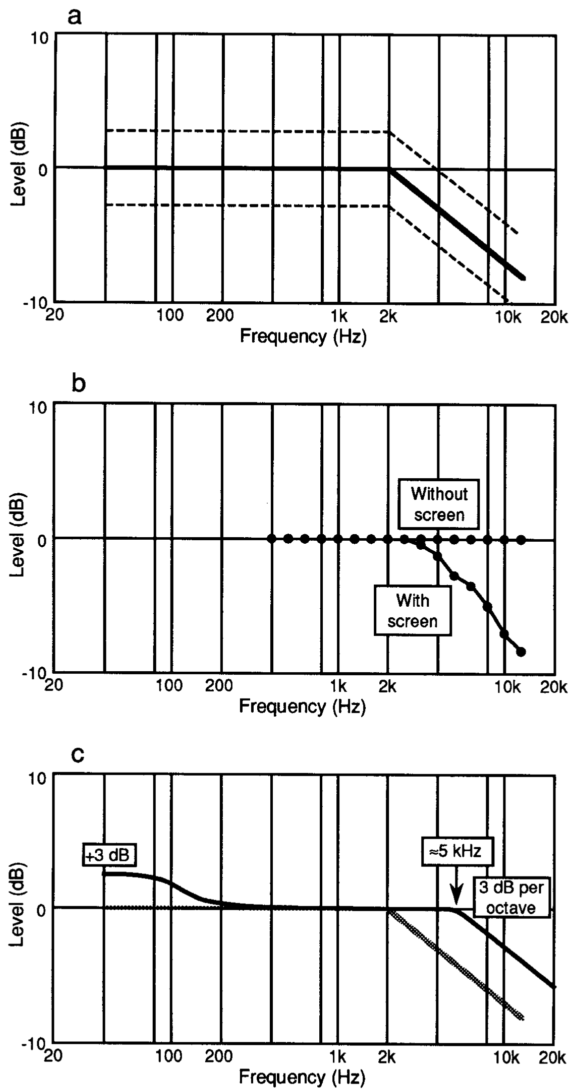
Another important step in correlating the small room listening experience with the standard cinema is overall signal equalization. The cinema and dubbing theater are normally equalized to the ISO 2969 curve, shown in Figure 5a. Also shown here is the typical on-axis high frequency loss caused by the film screen at Figure 5b. When a film is brought into a video mastering studio, it will sound quite bright, inasmuch as there is no screen loss function to match the sound to that which the film mixers heard. This must be compensated for in the processing of film product for home video tape, Laserdisc, or for Video DVD. The final EQ must take into account the fact that high quality home loudspeaker systems are now being designed for fairly flat on-axis response out to 8 or 10 kHz. JBL's suggested guidelines for a target surround loudspeaker room EQ are shown in Figure 5c. This equalization is empirical and represents an average of consumer installations in which low frequencies may be slightly boosted by diminished sound absorption at low frequencies and rolled off high frequency response due to increased sound absorption at high frequencies.

Therefore, the mixing engineer must re-equalize all film channels to compensate for screen effects as well as the basic difference between the ISO 2969 curve and the normal conditions of home listening. For the most part, this has been done "by ear," but THX has outlined a rational approach to carrying out the entire film-to-consumer equalization chain.

6. The Surround Array for Music Only Applications:

There is considerable argument among engineers regarding surround loudspeakers for music-only applications. For pop-rock music, which is the bulk of recorded product, it is best

Figure 5. **ISO 2969 curve (a); typical on-axis screen loss (b); suggested room EQ guidelines for surround sound work environments (c).**

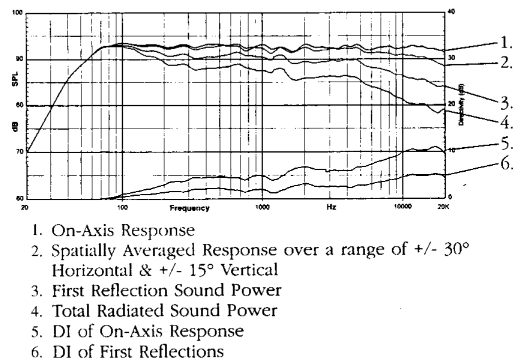


that all five loudspeakers be identical, at least in terms of HF and MF componentry. For classical music of the direct-ambient type (in which the surround channels carry primarily reverberant material for enhancing a sense of space), then dipole surrounds may be more appropriate. (THX has standardized on dipole surround loudspeakers as providing the most realistic translation of film surround program into the home listening environment.)

7. Loudspeaker Performance Attributes for Multichannel Sound:

As compared with two-channel stereo, surround mixing is a complicated affair. The two major differences between 5-channel surround sound and stereo are the hard center image and the stereo surround channels. It is important that the loudspeakers have very uniform response over their nominal listening angle of ±30° horizontally and ±15° vertically. JBL's new family of LSR (Linear Spatial Reference) monitors have addressed this attribute and routinely exhibit the on- and off-axis response shown in Figure 6. Designing the loudspeaker for uniform response over a wide listening cone results in smooth directivity indices (DI), indicating that power response in the listening space will be uniform. See JBL Professional Technical Notes, volume 3, number 2, for a more detailed discussion of Linear Spatial Reference.

Figure 6. **LSR32 family of on- and off-axis curves, plus DI curves.**

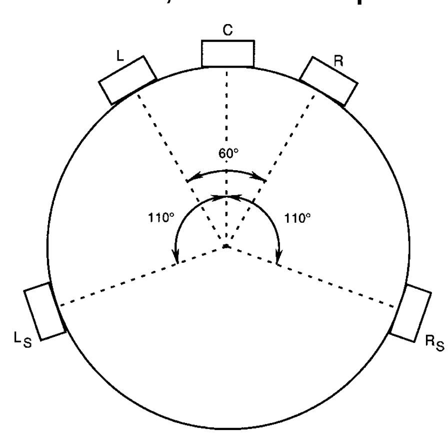


The greatest benefit of the center channel (the so-called hard center) is that the localization of a vocalist is no longer dependent on the listener's being in the sweet spot. Even a listener far off axis will immediately lock in on the center loudspeaker for a vocalist or other soloist. We can then expect that the listening space will accommodate more personnel, all of whom deserve to hear accurately, and the notion of LSR seems tailor made for this application.

8. Target Studio Layout:

The target L-C-R layout for a surround sound workplace calls for a nominal left-center-right included listening angle of about 60°, with the surround loudspeakers placed in the left and right at 110° (Brandenburg, 1996), as shown in Figure 7.

Figure 7. **Ideal listening setup for multichannel sound with five loudspeakers. (International Telephonic Union, ITU-R BS.775 publication)**



We will now discuss loudspeaker requirements and dimensional aspects for workspaces according to the typical room plan shown in Figure 8. Table 1 presents typical dimensions for workspaces of the room volume indicated.

Figure 8. **Typical studio workspace layout showing relative distances involved among prime listening location and all loudspeakers. (See Table 1)**

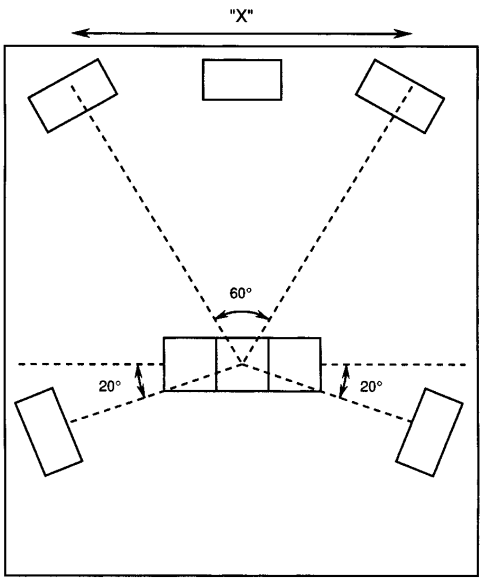


Table. 1 Suggested Guidelines for Surround Sound Loudspeaker Layout:

Room volume: (cubic feet)	Dimension X:	Maximum SPL per loudspeaker at listening position:
2000	10'	99.3 dB (LSR28P)
3000	11.5'	98 dB (LSR28P)
4000	12.5'	101.5 dB (LSR32)
6000	14.5'	100 dB (LSR32)
>6000	"	101 dB (4425)
	"	104.7 dB (4430)
	"	108 dB (DMS-1)

In most cases, as shown here, the front loudspeakers are placed in a line, making the center loudspeaker slightly closer to the primary listening position. Likewise, the two surround loudspeakers may be slightly closer. Ideally, these three monitor channels should be signal delayed so that arrival times from all five channels are the same at the prime listening position.

Reference Levels at the prime listening position:

It is standard practice to set reference acoustical listening levels so that each channel, driven at a nominal level of -20 dBFS (-20 dB *re* full level digital modulation) produces an acoustical level at the prime listening position of 82 dB, measured using the C-scale on a standard sound level meter. The measurement is made using a wideband pink noise signal.

Low Frequency Management:

The number of subwoofers will depend on the size of the installation and the nature of the work to be performed. For a small-room system composed of LSR28 loudspeakers, a pair of LSR12P should be sufficient. If the system consists of LSR32 loudspeakers, we recommend one LSR12P subwoofer for each of the front loudspeakers. For larger installations a careful accounting of acoustical levels desired should be made, and the JBL Model 4645B should be considered.

Subwoofer Placement:

While the placement of the front channels is laid out along desired sightlines and subtended angles, subwoofer placement is not always so clear. Another question is whether multiple subs should be driven in stereo or in mono. First, let us consider the problems of loudspeaker location in the room.

In the presence of normal program material it is relatively difficult to assign a specific direction to a sub channel if it has been crossed over (low-passed) in the range of 100 to 150 Hz. Therefore, the user has a good bit of leeway in picking the position that provides the best loading of the subwoofer by the listening room.

Subwoofer performance is affected by the distribution of low frequency *room modes* in the listening space. Room modes are specific resonances in the room itself and will reinforce the low frequency response. As a general rule, only the first and second *longitudinal* modes, those that exist between parallel boundaries, will be significant.

It is important that there be sufficient boundary absorption on all major surfaces in the studio environment in order to damp the modes to some degree. If this is not done, the low frequency response in the room is apt to be irregular and with a boomy quality.

For best results the subwoofers should be placed against the front wall, on the floor, below the left, center, and front loudspeakers. If there is a single subwoofer, placed it toward one of the front corners, adjusting its position by carefully listening or by measuring its response at the primary listening position with a real-time analyzer.

There is no question that maximum low frequency response will be achieved when the subwoofer is directly in the corner — but that response may not be the smoothest possible. Moving the subwoofer as little as 6 or 8 inches along the wall may be all that it takes to achieve smoother response.

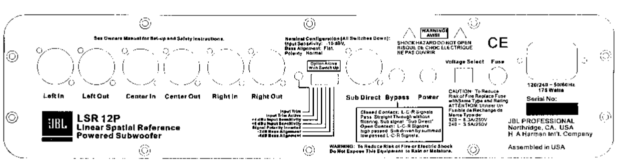
If more subwoofers are used, try first to array them along the front wall in a symmetrical array, left to right. Before you apply any electrical equalization to the subwoofer channel, try first to get the smoothest possible response by physical placement of the subwoofers.

Many audiophiles routinely operate a pair of subwoofers in stereo, left and right. While this is correct in principle, it may wasteful of acoustical power when there are significant low frequency out-of-phase signals present between the stereo channels. We recommend that the sub channels be driven by either the “0.1” effects channel (which of course is mono), or by the combined low frequency summation of the main channels.

There are a number of PC programs that can be used to calculate the normal modes in a rectangular space, indicating probable loudspeaker locations for smoothest response.

When the LSR12T models are used, it is possible to drive them with the low-passed frequency content of the three screen channels. This is shown in Figure 9, where the Left, Center, and Right channel sources are looped through the system electronics. When the Bypass switch is opened, the three screen channels will be high-passed, and their combined low frequency program content will be fed to the subwoofer amplifier.

Figure 9. **Rear view of electronics, LSR12P.**



Alternatively, when a 5.1 channel source, such as a film mix, is used, the subwoofer would be fed from the .1 channel using the Sub Direct input with the Bypass switch engaged.

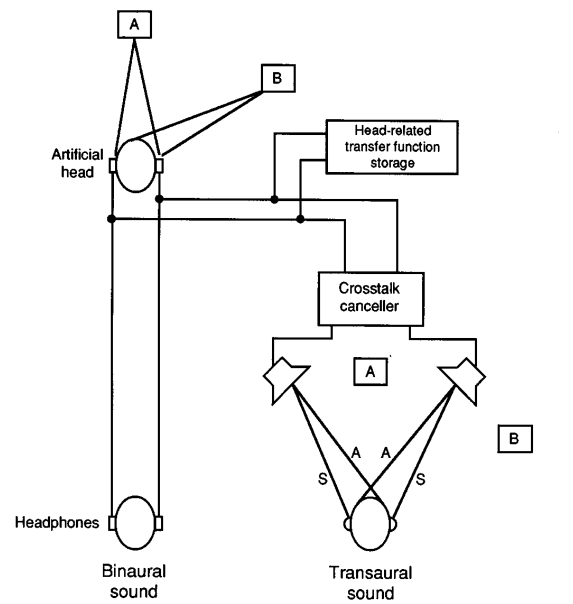
In either case, the specific LF response of the LSR12P units can be fine-tuned using the LF input trim, polarity, and alignment controls.

9. Outlook for the Future: Virtual Surround for Computers:

The term “virtual surround” has reference to one of several methods of creating a surround sound field around the listener’s head by the use of only two loudspeakers. Basically, the technique uses signal cancellation at the ear positions so that a binaural sound field can be created directly at the ears of the listener. The technique works best when the listener is in a fairly well defined listening position, and not varying from that position to any significant degree. Applications here include many computer game applications and certain home TV applications where the listener’s position can be clearly defined and maintained.

The various techniques that support virtual surround will require multichannel discreet sound sources, and as such the producers of virtual surround encoded program material will certainly use postproduction houses that are equipped to make multichannel mixes. Figure 10 presents a simplified signal flow diagram for producing Harman’s patented VMax virtual surround effect.

Figure 10. **Principle of VMax.**



10. JBL Multichannel Sound Loudspeaker Specifications:

	Freq. Respon. (-6dB):	Power:	Sensitivity:	Dimensions:
LSR32	40-22kHz	200W IEC	90dB	406 x 330 x 325mm 16 x 13 x 12.75 in
LSR28P	37-22kHz	200W IEC	90dB	635 x 394 x 292mm 25 x 15.5 x 11.5 in
LSR12P	25-110Hz	200W IEC	90dB	635 x 394 x 305mm 25 x 15.5 x 12 in
4425	40-16kHz	200W IEC	91dB	635 x 406 x 311mm 25 x 16 x 12.25 in
4430	35-16kHz	300W IEC	93dB	908 x 552 x 400mm 35.75 x 21.875 x 15.7 in
DMS-1	28-20kHz	600W IEC	95dB	914 x 584 x 527mm 36 x 23 x 20.75 in

11. Multichannel Sound Glossary:

4-2-4: Matrix terminology indicating that four discrete channels have been matrixed into two, for eventual playback over four monitor channels.

5.1 channels: Indicates standard digital playback in the cinema and home, with five full bandwidth channels and a single effects channel (>150 Hz).

AC-3: Refers to the Dolby perceptual encoding method for multichannel presentation in the cinema as well as in the home.

Diffuse surround: Refers to surround loudspeakers that produce a uniformly diffuse coverage of the listening area.

Dipole: Refers to a loudspeaker with a figure-8 radiation pattern used in the home; the null of the pattern is normally pointed at the primary listening position.

DTS: Stands for Digital Theater Sound, a perceptual coding method for 5.1 presentation in the cinema and the home.

Dolby Prologic: Refers to Dolby's matrix playback method for improving channel separation in the cinema or home.

Dolby Digital: Refers to Dolby's AC-3 5.1 digital system.

Downmix: The procedure of mixing a number of multichannel signals into a lesser number of monitor channels.

DVD: Stands for Digital Versatile Disc, a consumer medium for both digital video and audio.

LCRS: In Dolby stereo matrix playback, stands for left-center-right-surround.

LFE: Stands for low frequency effects channel, or the .5 channel in cinema digital systems.

L_T, R_T: Stands for left-total, right-total, indicating the stereo pair of signals used to drive the Dolby stereo playback matrix.

L_E, R_E: Stands for left-extra, right-extra, indicating the added two loudspeaker positions behind the screen for a five-channel presentation in the cinema.

Monopole: Indicates a point source loudspeaker, such as would be used in multiples in the cinema.

MPEG-2: Stands for Motion Picture Experts Group - 2, a professional group activity that has supervised the development of perceptual coding standards for both video and multichannel audio.

Perceptual Coding: Any system for encoding video or audio making use of masking phenomena in effecting a reduction of transmission data rate.

Point source surround: Indicates a surround system in a cinema or dubbing theater composed of point source (monopole) loudspeakers.

SDDS: Stands for Sony Dynamic Digital Sound, Sony's proprietary eight-channel perceptual encoding system for the cinema.

Stems: A motion picture production term indicating the multichannel audio tracks containing effects, dialog, and music that comprise the input to the final mixdown to the print dubbing master.

UltraStereo: A commercial noise reduction system for the cinema that is compatible with Dolby analog noise reduction systems.

Virtual surround: A surround effect generated by a single pair of loudspeakers located fairly close to the listener's head.

References:

K. Brandenburg, "Introduction to Perceptual Coding," *Collected Papers on Digital Audio Bit-Rate Reduction,* Audio Engineering Society, 1996.

T. Holman, Standards Report on DVD Audio, *J. Audio Engineering Society,* volume 45, number 12 (December 1997).

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