WHITEPAPER

Cinema audio: How new technologies are helping realize DCI audio specifications

Introduction

Since the introduction of the Digital Cinema Initiative[1] (DCI) standards in 2002, moviegoers have been enjoying the highest quality visual experience ever offered by exhibitors. With innovations such as high-frame-rate, 4K digital and 3D projection being offered along with larger screen sizes and higher-capacity auditoriums, filmmakers have been able to use the improvements in visual presentation technologies to push the boundaries of cinematic creativity and expression.

However, despite the advances in projection, the audio aspect of the cinema experience has yet to realize the potential of the DCI audio standard. Legacy audio systems based on film-era technologies are still the standard in today's cinema auditoriums. Furthermore, as new digital audio and immersive formats are developed and released, these legacy systems are limited in their ability to accurately reproduce these new formats. This means there is an opportunity for exhibitors to outfit their auditoriums with cutting-edge audio systems for a greatly improved and consistent audio experience.

Part 1 – Legacy audio systems

Cinema audio systems are traditionally divided into two sections: the A-chain and the B-chain. The A-chain is the portion of the system that contains the "soundtrack," printed on the film or on external media, and the associated equipment to playback the audio tracks. This includes all the required decoding, re-equalization/de-equalization (pre-emphasis/de-emphasis) and synchronization.

Today's typical movie theater employs legacy systems for the audio B-chain[2] based on technology that was developed during the 35mm film era. Figure 1 shows the complete audio system block diagram for film-based projection.

The B-chain in legacy installations refers to the crossover, post-equalization, power amplifiers and loudspeakers. These systems typically have two-, three- and in some instances, four-way loudspeaker designs for the screen channels. These loudspeakers use hornloaded compression drivers for the high frequencies with cone-type drivers, either as direct radiators or in some cases horn loaded, for the lower frequencies. The surround loudspeakers are usually two-way design using similar transducers to those used for the screen channels. The loudspeakers are powered with transistor-based Class AB power amplifiers, many of which use linear power supplies.

Figure 1 – Complete theatrical audio reproducing chain – film-based projection

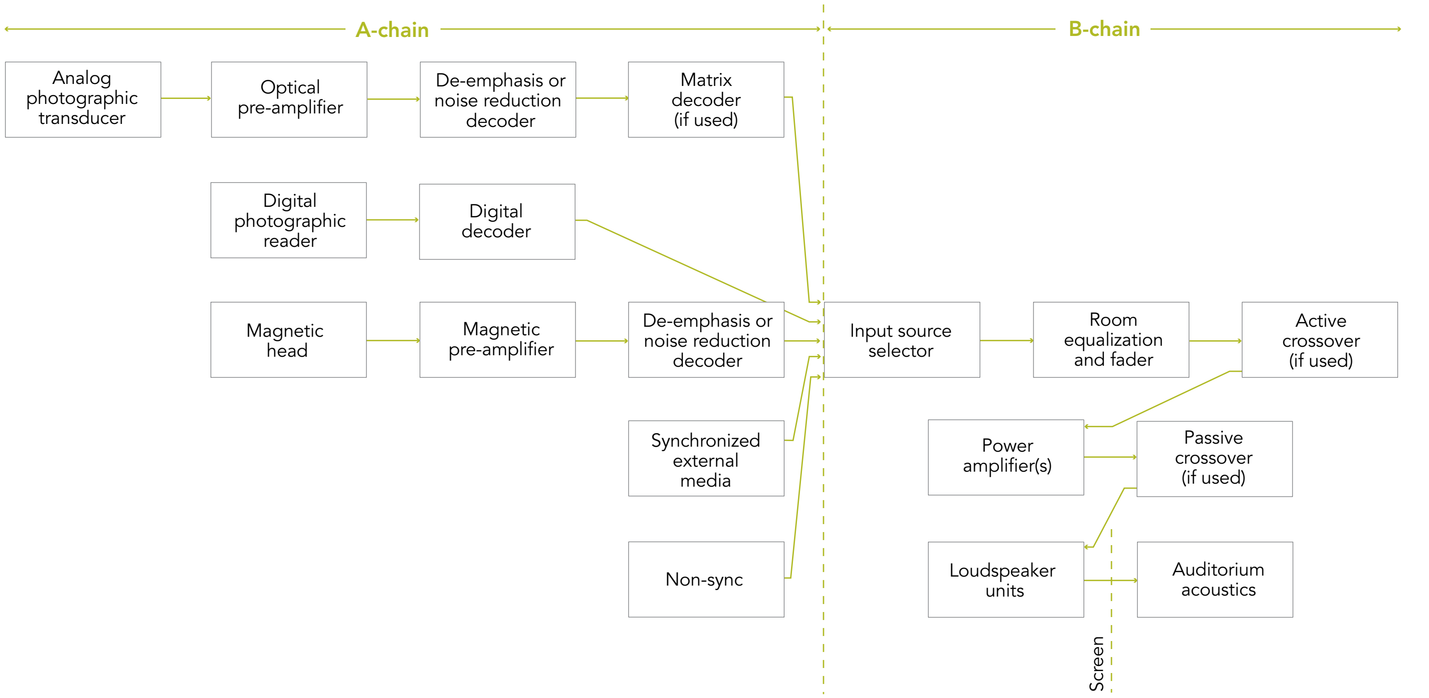
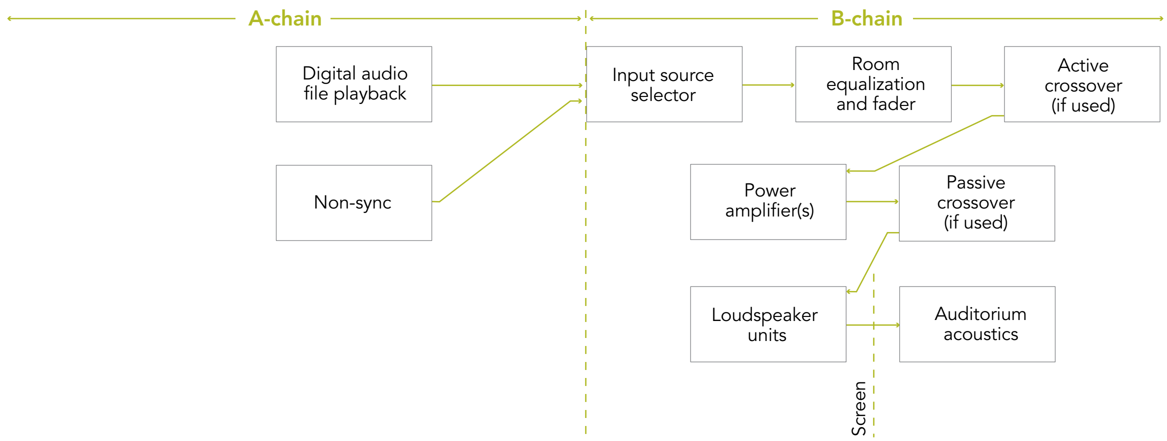


Figure 2 – Complete theatrical audio reproducing chain – digital cinema



Legacy audio formats

The overall quality of the early digital audio formats, such as Dolby Digital[3], DTS (now Datasat Digital Sound[4]) and Sony Dynamic Digital Sound (SDDS)[5], was limited by the available bandwidth of the storage medium, film, which required the use of digital audio compression with a maximum effective resolution of between 16 to 18 bits per sample at a sample rate between 44.1kHz to 48kHz.

The theoretical maximum dynamic range for a 16-bit depth audio signal is 96dB, while for an 18-bit depth audio signal it is 108dB. The greater dynamic range afforded by the digital audio formats, over that from the best 35mm film optical tracks, even with Dolby noise reduction, placed new demands on cinema audio systems. For some cinema audio systems, the DCI content demands were, and for some are, at the limit of, and sometimes beyond, their performance envelope.

The DCI audio standard

The DCI was created in 2002 and is a joint venture between Disney, Fox, Paramount, Sony Pictures Entertainment, Universal and Warner Bros. Studios. The DCI audio specification, created in 2005, allows for extremely high quality, uncompressed linear PCM[6] digital audio formats with a maximum resolution of 24 bits per sample and up to a 96kHz sample rate. With the theoretical dynamic range of 144dB for the specified 24-bit depth, the demand on the legacy cinema systems is even more extreme than that from the earlier digital audio formats. The audio portion of a feature film is packaged with the visual, sub-title and metadata into a DCI compliant digital cinema package (DCP).

The DCI audio standards

- 20 or 24 bits per sample, 48kHz or 96kHz sample rate
- Up to 16 full bandwidth channels
- WAV container, uncompressed PCM audio

The DCI standard was developed to give exhibitors a common package that includes an audio format that has the potential to produce a more accurate reproduction of the original source material.

For many cinemas with digital projection systems, as seen in Figure 2, only the A-chain portion of the cinema audio system has been updated. The B-chain equipment is the same as that used before the change to digital projection.

[1] http://www.dcimovies.com/
[2] The B-chain is anything from the output of the sound processor to the loudspeakers, including the amplifiers, signal processors, and cabling.
[3] http://www.dolby.com/us/en/consumer/technology/home-theater/dolby-digital.html
[4] http://www.datasatdigital.com/cinema/
[5] https://en.wikipedia.org/wiki/Sony_Dynamic_Digital_Sound
[6] https://en.wikipedia.org/wiki/Pulse-code_modulation

Opportunity for improvement: Six common performance issues with legacy audio systems

Many current cinema theaters are not capable of realizing the potential of uncompressed DCI audio because they still utilize legacy audio technology components. The six most common performance issues with typical legacy audio systems are:

1 Power compression in the loudspeaker drivers

Despite improved magnetic motor design, compression drivers and woofers have their voice coils enclosed in a tight magnetic structure. Even with improved design elements, the operating temperature of the voice coils can reach 392˚F (200˚C). As the voice coil temperature rises, the impedance of the voice coil also increases, so the driver draws less power and the sound level output creeps downward.

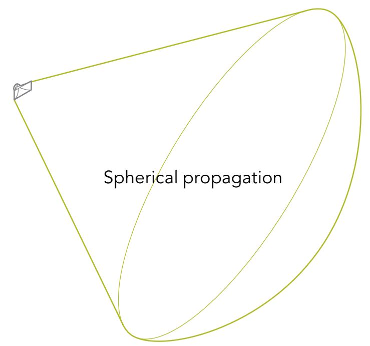
2 Directivity control (loudspeakers)

Many legacy cinema loudspeakers use horns attached to compression drivers for directivity control. These horns can use any of several methods to control the directivity, but whatever the method, the control is only effective down to a certain lower frequency determined by the horn mouth dimensions. In addition, directivity at higher frequencies can vary from that in the mid-frequency range of the design pass-band of the device. In a three-way system, the directivity of the drivers can differ at the cross-over frequency between the low- and mid-frequency drivers and between the mid- and high-frequency drivers resulting in ragged and uneven coverage. A two-way system has a similar directivity mismatch between the drivers, albeit just one.

3 Distortion

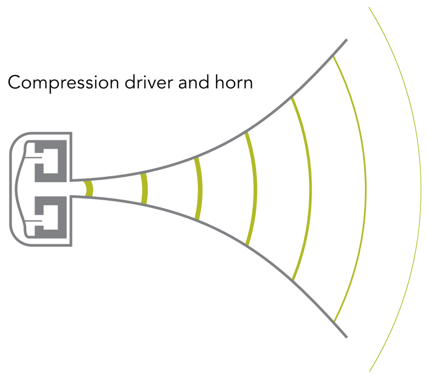
The compression drivers used with horns generate very high sound levels at their diaphragm. The sound levels at the diaphragm typically start about 120dB and can reach 154dB and higher. At these high levels, even if the magnetic motor, phase plug and diaphragm are perfect, the sound propagation in air (at the diaphragm, within the phase plug, and in the throat) is very non-linear due to the high sound level. As a result, the propagation of the sound in and of itself generates distortion products before the sound even enters the horn, and these distortion products grow larger the farther the sound propagates. Larger diaphragms, lower compression ratios, and other design trade-offs that can be used to lower these distortion products have their own problems. These problems include the potential for large diaphragms to have more breakup modes as well as lower output associated with lower compression ratios.

Driver dispersion patterns



▲ A typical compression driver has a spherical propagation pattern, which results in sound reflecting off ceilings and walls, reducing the overall clarity of the audio.

How drivers work



▲ Despite improvements in design and components, compression drivers and horns are susceptible to performance issues such as power compression, inherent distortion and non-linearity. Additionally, there is a detrimental interaction between horn loaded drivers and perforated screens, resulting in further distortion and non-linearity.

❹ Non-linearities

The cone type drivers used for mid-frequency reproduction and compression drivers typically used for high-frequency reproduction suffer from non-linearities, which are unrelated sounds/imperfections that are due to the break-up of the cone or compression driver diaphragm. These non-linearities become significant at medium sound levels and become progressively worse at higher power levels. Additionally, there is the noise from the other moving parts of the driver, such as the surround, and for cone type drivers the spider, as well as the inherent non-linearities of the magnetic motor system, all of which limit the dynamic range of the driver and become substantial as driver output increases. Non-linearities impact the listening experience, specifically: dynamic range, the signal-to-noise difference, headroom and transient response.

Dynamic range is the difference between the audio system's highest sound level and the lowest sound level. Dynamic range is limited by the distortion caused at high sound levels and at the low end by the "self-noise" of the driver due to, but not limited to, the diaphragm or cone material, the lead-out wires and voice coil rocking. Limited dynamic range means limited signal-to-noise difference between the average signal level and noise. This also impacts headroom, which is the difference between the peak output level (the upper limit of the dynamic range) and the average signal level.

Transient response is a measure of the ability of a device to respond to rapid changes in the signal, such as that from the sound of a special effect, and is a function of the driver's motor strength, the mass of the driver's moving parts, and the voice coil design. Cones and diaphragms have mass and this mass requires energy to set them in motion. Once in motion the mass of the moving parts has momentum and this limits the high-frequency response of the driver as the time to change the motion of the driver's moving parts increases with mass.

❺ Screen Effects

In most cinema theaters the screen channel loudspeaker systems are mounted behind a perforated screen. Even with treatments such as micro perforations, the screen is not completely transparent to sound. Sound attenuation by the screen starts at the upper-bass frequencies and this attenuation increases as the frequency increases. In addition, the distance of the mid- and high-frequency loudspeakers from the screen can also cause unwanted effects. The separation between screen and driver causes reflections between the two, so a delayed version of the signal is added to itself, causing constructive and destructive interference.

❻ Amplifier Efficiency

Each driver in a bi-amp, tri-amp or quad amp cinema loudspeaker system requires a dedicated power amplifier to be connected only to that driver. Many cinemas are using legacy power amplifiers that use a Class AB type topology, which can have poor transient response and low energy efficiency. Poor transient response means that the amplifiers are slower to react to rapid changes in incoming signals. Low power efficiency, or conversion efficiency, means most of the input power is wasted as heat and not delivered to the load. While this may not be seen as expensive in terms of the electricity consumed, the heat load can have more serious cost implications as the heat needs to be controlled by the HVAC system – in terms of greater capacity for the HVAC units, larger duct runs and higher operating costs.

Part 2 – Realizing the potential

Key performance requirements for cinema audio and the benefits of ribbon driver-based audio systems

An integrated systems approach, utilizing new designs and technologies, can enable cinemas to realize the potential of the DCI audio soundtrack. To achieve the potential of DCI audio, every link in the signal chain, starting with content sources, through the audio processing and amplification, to the extended range loudspeakers and the subwoofers, needs to be considered.

Specific performance features that make up the integrated cinema audio system should include the following:

1 Content Sources

Storage – The integrated media block (IMB) or cinema server (which decodes the DCP content), and for the B-chain, provides uncompressed, linear PCM encoded, up to 24-bit, and up to 96kHz sample rate, DCI compliant, for the up to 16 channels in the package (DCP). The IMB is at the end of the A-chain and at the beginning of the B-chain.

Alternative content sources – Include, but are not limited to, the latest high quality, lossless audio formats such as Dolby TrueHD[7], DTS HD-Master Audio[8] and other linear PCM formats. The audio from these sources can have up to 24-bit depths and up to a 192kHz sample rate. The number of channels can, and does, vary depending on the source and the material.

2 Audio processing

The DCP audio signal is a multi-channel stream encoded in one or more of the several audio encoding schemes available today. The DCP uses the Material Exchange Format (MXF)[9] for the packaging of the PCM audio, which can be a compressed version of the original audio. The signal processing requirements of the PCM audio signals include:

- Support for up to 16 channel of DCI audio input
- Ability to decode lossless alternative content audio formats
- High quality 24-bit per sample digital to analog conversion
- High signal-to-noise ratio
- High dynamic range
- Phase linearity

3 Amplifiers

Class D[10] amplifiers offer performance advantages in faster transient response, high power output, and high efficiency compared to Class AB and other designs now used in many theaters.

Faster transient response – A faster transient response allows for reduced distortion so the program material is reproduced with greater accuracy, without the brittleness found in amplifiers with a slower transient response.

High power output – The smaller form factor of a Class D amplifier means that higher power outputs are possible with less space than what is needed for the equivalent output in an analog design.

Higher efficiency – Compared to Class AB and other analog transistor amplifier designs where efficiencies are typically about 50%, Class D power amplifiers can achieve practical efficiencies approaching 90%.

Higher efficiency means more of the input power is delivered to the loudspeakers and less power is generated as wasted heat by the amplifiers, directly reducing energy consumption and a lower cost of operation. In addition, less heat build-up from amplifiers can also indirectly reduce energy consumption and provide additional savings, due to reduced requirements for air conditioning to remove waste heat.

4 Loudspeakers

Cinema loudspeakers traditionally employ compression driver technologies, however, line arrays and ribbon driver technologies are recognized as providing superior audio for systems in cinema applications. A ribbon driver diaphragm features a low mass, flexible membrane with a voice coil printed or mounted to it. The voice coil is flat (on a plane) and interacts with the magnetic field of magnets placed on either side of the planar diaphragm. Ribbon driver loudspeakers offer several performance advantages compared to compression driver/horn and cone-type loudspeakers.

Minimal power compression – Ribbon drivers have lower power compression compared with cone-type and compression drivers, where the voice coil is in a constrained space with limited air flow. The structure is open on a ribbon driver diaphragm and though air is not a good conductor of heat, the increased open surface area for the conductors, compared to compression drivers and cone-type drivers, offers improved heat transfer from the diaphragm to the surrounding environment, so operating temperatures can be lower for a given sound level.

7 http://www.dolby.com/us/en/consumer/technology/home-theater/dolby-truehd.html
8 http://www.dts.com/professionals/sound-technologies/codecs/dts-hd-master-audio.aspx
9 http://www.digitalpreservation.gov/formats/fdd/fdd000013.shtml
10 http://www.irf.com/technical-info/appnotes/an-1071.pdf

Lower distortion – Unlike compression drivers, ribbon drivers do not suffer from high frequency breakup, in part due to the lower mass of the diaphragm –typically about 1/30 the mass of a compression driver. Since the voice coil is in contact with the planar diaphragm, the driving force covers a large percentage of the flat diaphragm surface, which further reduces distortion due to diaphragm breakup and other issues found in compression driver domes, where the voice coil is at the perimeter of the diaphragm.

Faster transient response – Since a ribbon driver diaphragm has less mass than a compression driver, the overall rate of acceleration/deceleration of the ribbon driver diaphragm can be faster, due to lower momentum, leading to better transient response. This is ideal for digital cinema content with a high crest factor.

Higher dynamic range – The faster transient response that a ribbon driver offers due to the direct-drive low-mass design increases the available dynamic range by approximately 10 to 12dB when compared to compression drivers where the momentum of the diaphragm must be overcome to accelerate the diaphragm and then overcome again to change direction.

Extended high frequency response – Ribbon drivers offer an extended high frequency response compared to compression drivers. This is due to the direct drive of the flat voice coil attached directly to the planar diaphragm, compared to the losses found in compression drivers as the voice coil vibrations need to first travel up the voice coil bobbin, through the joint between the bobbin and the diaphragm, and the interference of the sound as it transits into and then back through the diaphragm.

In addition, the wound voice coil used in compression drivers is an inductor, so the coil itself has losses that increase as frequency increases. In a ribbon driver, the inductance of the flat planar conductors is much lower.

❺ Ribbon driver based line arrays

Ribbon drivers are ideal building blocks for line arrays, due to their inherent cylindrical propagation characteristics. This form factor allows for a precise continuous vertical column array of the ribbon drivers. A columnar line array of ribbon drivers offers advantages over the horn used with compression and cone-type drivers. Most horn loaded systems have uneven horizontal and vertical dispersion and therefore uneven coverage at the periphery of the listening area as well as a difference in sound level from the front to the back of the cinema auditorium.

A columnar line array comprised of ribbon drivers and small cone-type drivers offers highly controlled directivity and extremely even coverage. As the column length increases, the vertical coverage at the low end of the column bandwidth becomes tighter. By curving the line array, and varying the signal to each of the drivers in the array, the dispersion of a column array can be better matched to the listening area and can have better and more even coverage. In theory, a line array system has only 3dB of attention per unit of distance, compared to a point source system, which has 6dB of attenuation per unit of distance.

As a result of this reduced attenuation over distance, a ribbon driver-based line array system can have a variation in sound levels of only ± 2dB throughout the entire listening area in a typical auditorium.

❻ Subwoofers

Reproducing the low-frequency portion of cinema soundtracks, subwoofers provide a significant impact. High-performance subwoofers feature the following characteristics: high power handling, reduced power compression and high cubic displacement cabinets, offering extended low frequency response. Utilizing subwoofers to extend the bandwidth of screen channels and even surround channels, enables reproduction of low frequency content present in cinema soundtracks, which would otherwise be lost.

The new era:

Matching sound with visuals

Cinema projection technologies have dramatically improved the visual experience in recent years. However, there has been an industry-wide lag in the implementation of cinema audio systems that can take advantage of the high-performance potential of the DCI audio standard. As audiences have grown accustomed to impressive visuals, their expectation for an immersive audio experience has also been raised.

Since the whole is often more than the sum of its parts, exhibitors looking to realize the potential of DCI audio must utilize a fully integrated systems approach. Leveraging solutions based on ribbon driver technology, line array loudspeaker designs, high-performance subwoofers and Class D amplification to provide audio systems capable of realizing the enormous potential of DCI audio. Exhibitors are now able to offer an enhanced audio experience to customers, improving the movie going experience and differentiating themselves from competitors.

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