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A MAJOR DEVELOPMENT IN MOTION PICTURE LOUDSPEAKERS: SOLVING THE "SCREEN PROBLEM"

BY

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As long as motion picture theatre loudspeakers have been placed behind a perforated screen, the insertion loss and interference encountered from the screen have been accepted as unavoidable. Much like the weather, everyone talks about it but, until now, few have offered more than "band-aid" solutions to do anything about it. A recent multi-way speaker loudspeaker has been employed which incorporates specific features designed to reduce these problems to practical insignificance.

This article describes a series of measurements of a four-way motion picture loudspeaker designed for placement behind the screen. Designed by Paul W. Klipsch and Gary Gillum, the TMCM-4 speaker system features flat mouth horns of minimal height which substantially reduce behind-the-screen reflections. For the first time, beamwidth angles are successfully shaped and tailored to produce a very consistent wideband coverage through a motion picture screen. In addition, beamwidth shaping is also used to "self-equalize" the axial frequency response of the system over the controlled horizontal beamwidth, totally eliminating the need for 1/3 rd octave treble equalization in the theatre.

Also for the first time a specially designed super tweeter with a very small flat mouth is incorporated to deliver the upper most frequencies through the screen, while maintaining a desirable coverage pattern. Comparisons with another typical theatre loudspeaker are included here as a reference.

BACKGROUND

Screen interference of several types exists. Among them are insertion loss, behind-the-screen reflections and beamwidth variations or distortions. Our findings show that the typical practice of using a two-way speaker system behind the screen, which includes a single horn loaded high frequency device for the octaves above 500 Hertz (Hz), does little

to address these effects. The curved shape of the mouth of many such horns, for example, guarantees large amounts of sound energy will be reflected behind the screen, These reflections can only be re-reflected back through the screen unless they are somehow absorbed at an additional cost. Placing high frequency horns (curved mouth or not) away from the back of the screen can only make this problem worse.

Such practices have become commonplace. In recent years theatre sound system designers have often had little choice but to use loudspeakers that were primarily designed for public address purposes. Motion picture applications were an afterthought. A modern loudspeaker specifically refined for use in movie theatres, can be made to offer solutions to the unique problems encountered by transmitting sound through a screen.

The four-way theatre speaker described here is a fully horn loaded system with crossover frequencies at 350 Hz, 1000 Hz and 6000 Hz. The nominal beamwidth of the system above 500 Hz is 60° horizontal, by 40° vertical. The beamwidth is not constant. As we shall show, constant beamwidth per octave is not desirable. Rather, the radiating angles are carefully contoured to provide flat frequency response and even coverage throughout the theatre, while projecting through the screen.

The horizontal radiating pattern, or beamwidth as it's called, has been tailored by employing a super tweeter with a smaller radiating angle than that of the midrange horn. In addition, the high frequency vertical beamwidth, beginning at about 2000 Hz, is consistently reduced as the frequency increases. These coverage angle shapings have proven effective in overcoming the beamwidth distortion caused by the perforated movie screen. Other benefits have also been realized and will be described.

The following tests of the four-way system are referenced to a modern two-way system offered for theatre use. This system employs a direct radiator low frequency section. It is crossed over at 500 Hz to a large tweeter horn featuring constant horizontal and vertical coverage angles. Both of the speaker systems measured for this article are currently used in contemporary motion picture sound systems.

SCREEN EFFECTS

BEAM-SPREADING

Work of others, over the last 60 years, has confirmed the beam-spreading effect of a movie screen as the frequency increases [1] [2] [3]. This effect would seem to occur with every known high frequency horn. However the beamwidths of different horns are effected differently when placed behind a screen.

Polar response, or beamwidth, data was collected using a Time Energy Frequency (TEF) analyzer. This system allows measurements of near anechoic accuracy in a reverberant environment. Both The four-way and two-way systems were measured with and without the screen in front of them. This reveals the exact effect that the screen has on each system.

To more closely approximate the speaker placement in a theatre, the speakers were mounted on a turntable some 6 1/2 feet off the ground. The measurement microphone was placed approximately 30 feet from the speaker where the audience would be. In order to observe the combined vertical and horizontal beamwidth of each system from a listener's perspective, the microphone was placed 5 feet above the ground, which is about 11° below the axis of the high frequency sections of the speakers.

Table 1: Beamwidth data is listed as the degrees off the speaker's axis where the sound level drops 6 dB below the on axis level. The data is shown for both speaker systems, with and without the screen. Since neither system was effected by the screen at frequencies below 2000 Hz, these points are omitted.

HORIZONTAL BEAMWIDTH DATA ±3°

APPROXIMATE FREQUENCY	TWO-WAY SYSTEM WITHOUT SCREEN	TWO-WAY SYSTEM WITH SCREEN	FOUR-WAY SYSTEM WITHOUT SCREEN	FOUR-WAY SYSTEM WITH SCREEN
2000 Hz	100°	100°	60°	65°
2500 Hz	90°	90°	60°	60°
3200 Hz	90°	90°	60°	60°
4000 Hz	90°	90°	60°	60°
5000 Hz	100°	100°	55°	58°
6300 Hz	100°	100°	55°	55°
8000 Hz	90°	110°	60°	60°
10000 Hz	80°	115°	60°	58°
12500 Hz	80°	115°	40°	58°
16000 Hz	60°	65°	40°	58°

Table 1.

The reference two-way system is considered first. As expected, it does an excellent job maintaining its 90° beamwidth without the screen. With the screen in place, variations from the 90° pattern of ±25° are seen. The maximum beam-spreading effect reaches 20° to 35° at the 8 kHz, 10 kHz and 12.5 kHz frequencies.

Above 2 kHz, the four-way system maintains its target 60° beamwidth within ±5°, with the screen in place. The screen's beam-spreading effect with this system is greatest at the 12.5 kHz and 16 kHz frequencies. Since the high frequency beamwidth distortion of the screen is about 20°, maintaining a narrower 40° beamwidth out of the speaker at these frequencies, comes remarkably close to providing the desired 60° coverage angle beyond the screen.

Neither loudspeaker exhibited any meaningful lobbing either with or without the screen. Other horn designs have shown lobbing effects [4]. This suggests that there may be no hard and fast rules that can predict the effect a movie screen will have on a particular speaker. Each system should be evaluated individually.

These results lead us to conclude that if the beamwidth spreading effect of the screen is NOT constant with respect to frequency, and since constant horizontal coverage beyond the screen is desired, then horns with constant dispersion angles per octave are not the best choice for the cinema, if the speakers are behind the screen.

BEHIND-THE-SCREEN REFLECTIONS

It is often interesting to stand behind a screen while playing a theatre's sound system. If there are large reflections of the sound off the rear of the screen, one can often hear more pleasing and cleaner high frequencies behind the screen than one hears anywhere in the theatre itself. Obviously any sound bouncing around behind the screen isn't where it's supposed to be and is wasted. It should be a goal of the speaker's design, to transmit as much of its acoustic output as possible through the screen and into the theatre.

To measure the level of screen-reflected energy for each system, tests were done in an anechoic chamber. Each loudspeaker was measured with a swept sine wave and a 1/3 rd octave tracking filter. To assess the screen's reflections, the microphone was placed 2 feet above and to the right of the treble horn's axis, at a distance of about 1 foot behind the screen. Measurements were taken from this position for both the two-way and four-way systems, with and without the screen in place. These measurements are referenced to an on-axis frequency sweep with the microphone at a distance of about 2 meters. By the way the low frequency roll off observed in these tests is normal for these set-ups in this chamber and does not reflect the true low frequency performance of either system.

Figure 1: The two-way system, with its 2 x 2 ft. square mouth opening, shows no appreciable reflected energy below 2 kHz. Above 2 kHz, the sound level behind the screen is 4 to 10 dB below that found on axis. At 8 kHz to 10 kHz, the traces cross, indicating that there is more level behind the screen than on axis.

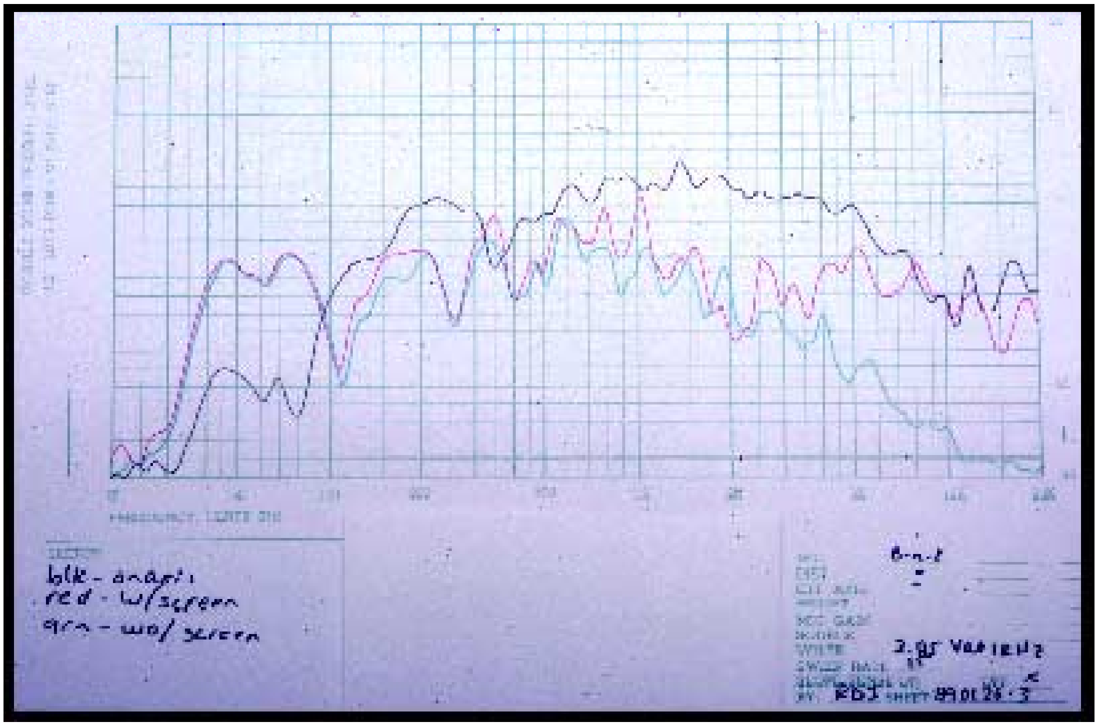

Figure 1.

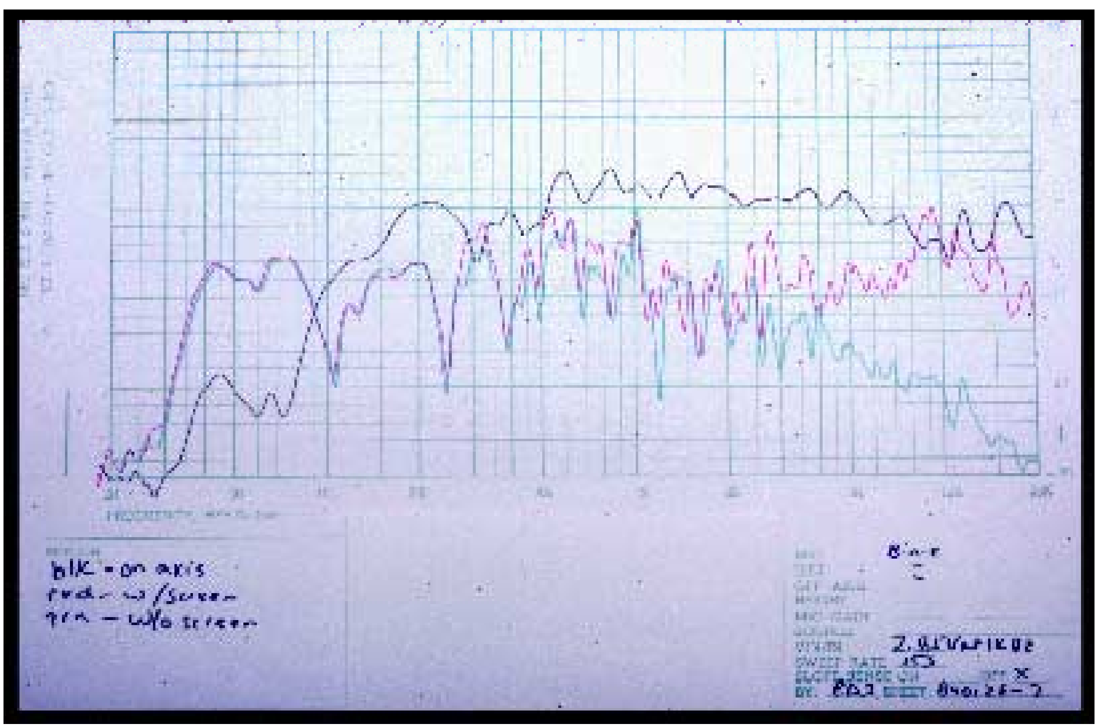

Figure 2.

Figure 2 reveals this effect to be more pronounced when the system is electrically equalized for a more flat on-axis response. Overall, these measurements indicate a significant amount of sound which does not, or now at least should not, get delivered to the audience. Absorptive materials would be required in order to prevent these reflections from bouncing back through the screen.

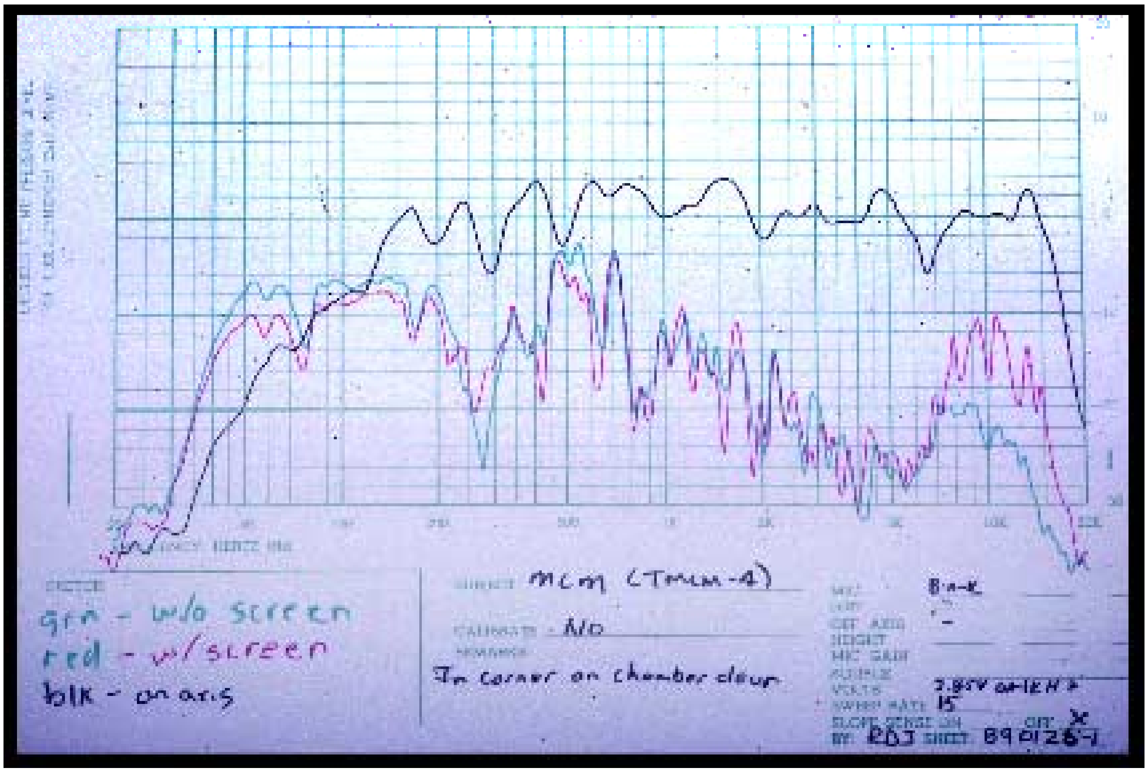

Figure 3.

Figure 3: As low as 500 Hz the four-way system exhibits less reflected energy behind the screen. Above 800 Hz we see from 10 to 20 dB less reflected energy than the reference two-way. The four-way system shows no appreciable reflections below 7 kHz. Above 7 kHz the reflections from the tweeter are consistently 10 dB below the on-axis level.

This reveals that the midrange horn is virtually immune to behind-the-screen reflections. Nearly all of the output from the midrange horn is transmitted directly through the screen.

The four-way system is designed with flat mouth horns which can be located so that their entire mouth openings are extremely close to the screen. The super tweeter is fitted with two horns, one above the other. Each tweeter horn has a mouth opening of about 2 x 3 inches, considerably smaller than would be possible with a two-way configuration.

As seen in figure 3 this construction provides a significant reduction in behind-the-screen reflections. Overall the four-way system exhibits a 10 dB improvement in avoiding behind-the-screen reflections, while avoiding them altogether for two additional octaves.

INSERTION LOSS

As with the reflection measurements, data on the insertion loss of the screen was taken in an anechoic chamber. Both the two-way and four-way systems were measured at 2 meters with a swept sine wave. Measurements with and without the screen in place were done. These tests show that insertion loss is relatively small for both systems.

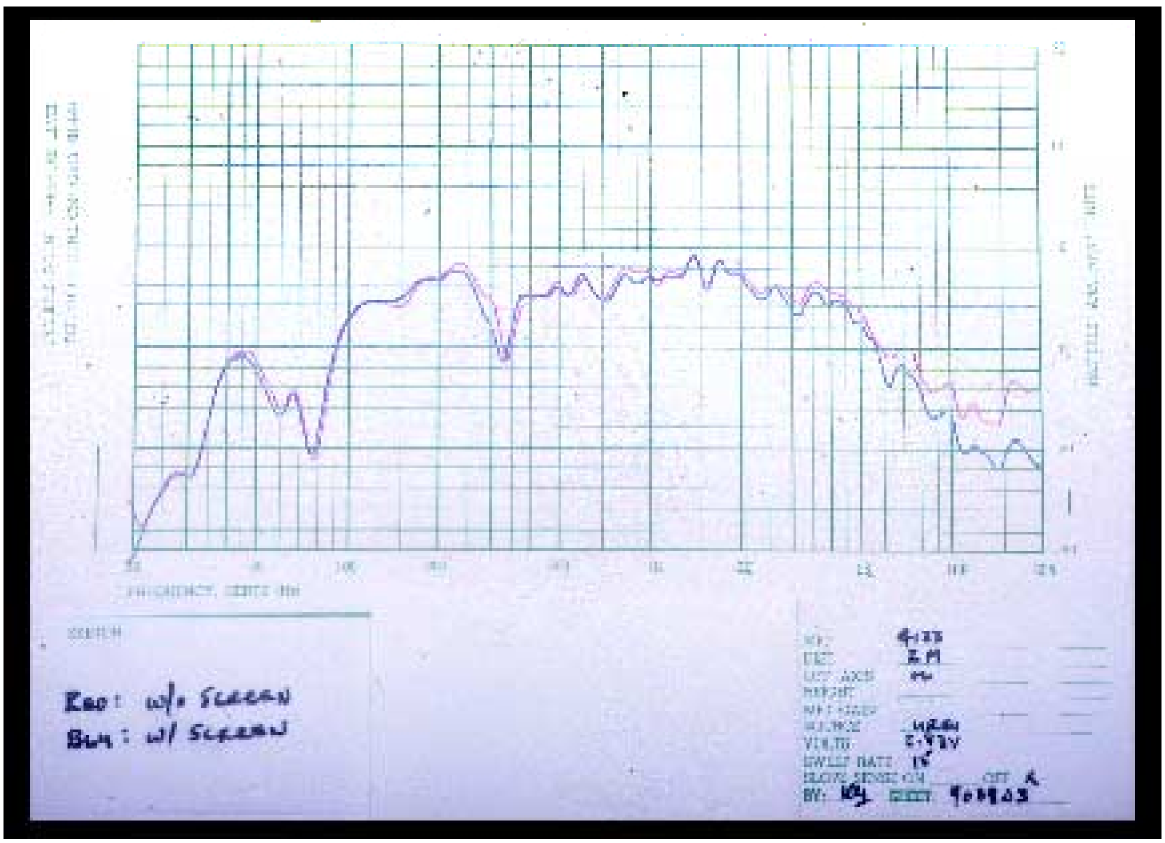

Figure 4.

Figure 4 shows the two-way system is generally unaffected by the insertion of the screen up to about 2 kHz. Above 2 kHz, the level reduction is about 1 dB up to about 7 kHz. Above 7 kHz, the reduction in level increases to an average of about 4 dB.

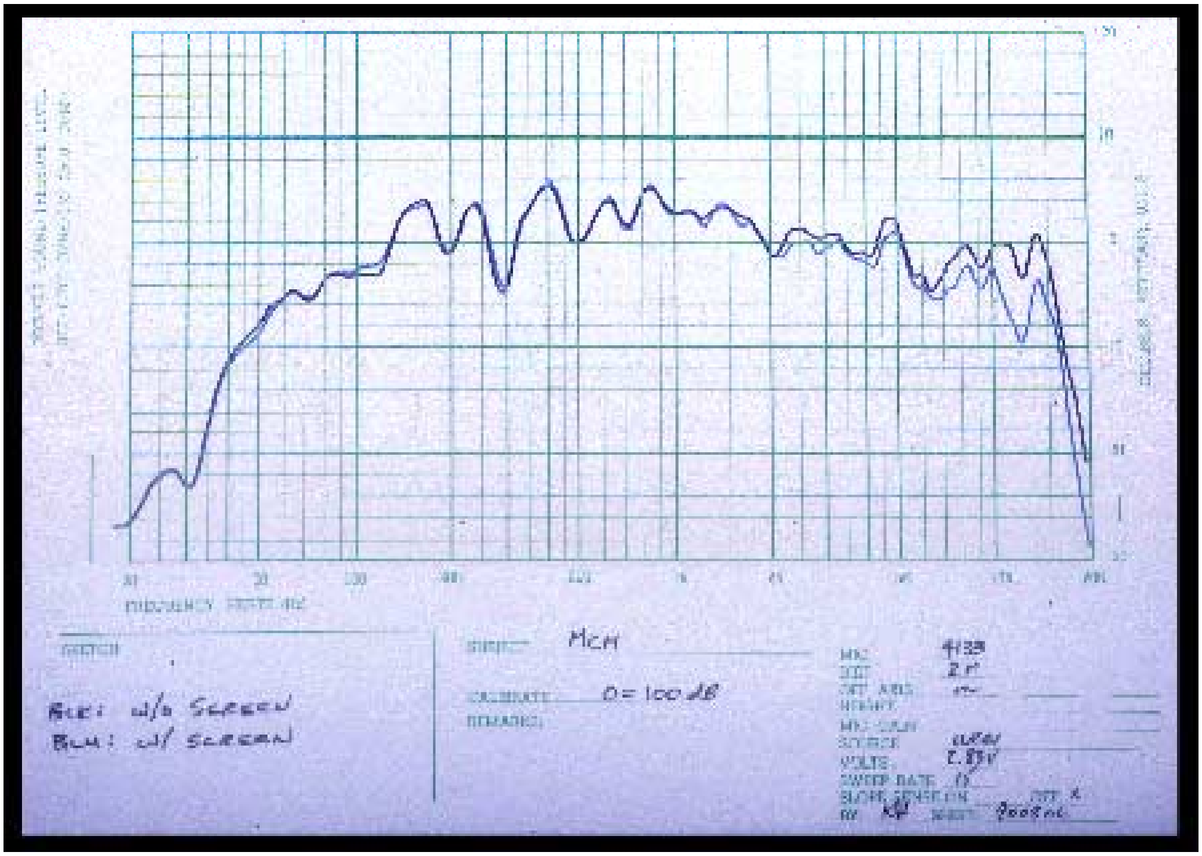

Figure 5.

Figure 5 shows that the screen insertion loss for the four-way system is essentially the same as the reference two-way system.

These small changes lead us to believe that the insertion loss of the screen itself, is (for these speakers at least) less important than previously believed. Since some of these decreases in level must be attributed to the beamwidth expansions exhibited by both systems with the screen in place, we see that the remaining actual loss, presumably caused by screen insertion, is rather minimal - perhaps as low as 1 to 2 dB.

DISCUSSION

As a practical matter the total screen interference encountered by the refined four-way system, can easily be compensated for with a minor increase of the treble control in the cinema sound processor.

The exponential midrange horn in the four-way system is self-equalized to compensate for the natural high frequency roll off of the compression drive system. The vertical beamwidth is reduced as the frequency increases, to provide for a flat axial response. Flat axial response across the desired horizontal radiating angle has long been regarded as critically important, for a speaker to be preferred by experienced listeners. This and other related findings have been explored at length by Toole [5].

To obtain the desired frequency response in motion picture theatre applications, non-self-equalized horns can require as much as a 15 dB boost at 16 kHz. The combined result of the self-equalized horn and the minimal tweeter loss through the screen, will allow the treble sections of the four-way system to meet the ISO-2969 frequency balance characteristic in the theatre, with only the aforementioned minimal treble adjustment. No special high frequency boost network, 1/3 rd octave or other form of equalization is required.

The coverage provided by the four-way system throughout the seating areas of large and small theatres alike, has typically varied ±3 dB or less in any 1/3 rd octave band from 400 Hz to 14 kHz. This has been achieved in theatres up to 160 feet long.

This indicates a second benefit from the vertical beamwidth shaping. In addition to providing a more nearly flat frequency response, concentrating the beam at the higher frequencies overcomes the high frequency loss of the atmosphere quite nicely. “Aiming” or concentrating more high frequencies toward the rear of the theatre allows the audience in the back of the auditorium to hear a normal spectral balance without making the sound in the front or other areas excessively bright or loud. The spectral balance heard throughout the theatre is found to be very consistent.

The vertical beam shaping enables the sound system designer to achieve such coverage while reducing the height of the screen speakers to an elevation of only 6 to 8 feet above the auditorium floor. Considering the picture, this puts the voices where the mouths are, so to speak.

CONCLUSION

The performance of a four-way fully horn loaded loudspeaker, refined specifically for use in motion picture theatres, has been evaluated with and without a perforated movie screen in place. This investigation has concentrated on the areas of screen-based beamwidth distortions, behind-the-screen reflections and screen insertion loss. Though insertion loss itself appears to be minimal, special design characteristics have been described which have been found to substantially overcome these interferences. Costly requirements such as heavy acoustic absorption behind the screen and as much as 15 dB in high frequency boosting circuits are eliminated. Excellent coverage is achieved in theatres of widely

varying sizes and shapes. Except for a minimal on-axis high frequency reduction, a loudspeaker refined specifically for the cinema can be expected to perform practically as though there is no screen in place at all.

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