The Royal Danish Theatre

By Per Kolding

Despite this facility's physical limitations, some rebuilding and a few revisions recreated its historical perspective.

The Royal Danish Theatre was built in 1748 in the center of Copenhagen. Because that building soon became too small to hold its attendees, it was rebuilt in 1773. The theater was heavily criticized for more than a century for its inner and outer physical condition.

"For a hundred years—God only knows how—this fragile house has stood up to the passage of time, in spite of the rat-infested canal in the neighborhood, and in spite of the fact that the ceiling and the floor came loose," the poet Henrik Hertz wrote in 1849.

Even after alterations to the entryways in 1837, to the seats in 1855, and to the stage building in 1857, the criticism continued.

In 1870, King Christian IX signed a law authorizing the construction of a new theater building, and on Oct. 15, 1874, the present "Old Stage Building" was opened. It was built next to the site of the old theater, which had been demolished in the meantime.

Toward the end of the century, the mechanical arrangements of the theater were declared hopelessly obsolete, so a legislative bill was introduced in 1899 that included provisions for improvements. The bill was sent into committee, and there it remained for 30 years.

In 1931, a new stage building for the Royal Theatre was built, and the original *raked* stage was replaced by a flat, revolving stage. The new building, often called *the starling's nest box*, was a combination of a theater and a broadcasting house, which is now primarily used for plays and musicals as well as for smaller ballets.

After much political debate, a bill authorizing the rebuilding of the Old Stage of the Royal Theatre was passed in June 1981, and reconstruction began in May 1983. The reconstruction included radical remodeling, and was carried out by Nils Kippel, the Royal Building Inspector, together with the architects Knud Holscher and Svend Axelson.

The entire backstage area of the old stage building was pulled down and rebuilt from cellar to roof. It now contains a wide array of modern facilities. The reconstruction only affected the audience area slightly—the orchestra pit has been made larger and more flexible, with the option of expanding into the first two rows of seats of the auditorium to seat a full symphony orchestra. Apart from this, the seating area has been virtually unchanged since 1874.

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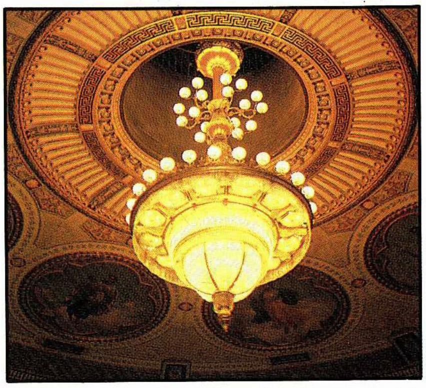
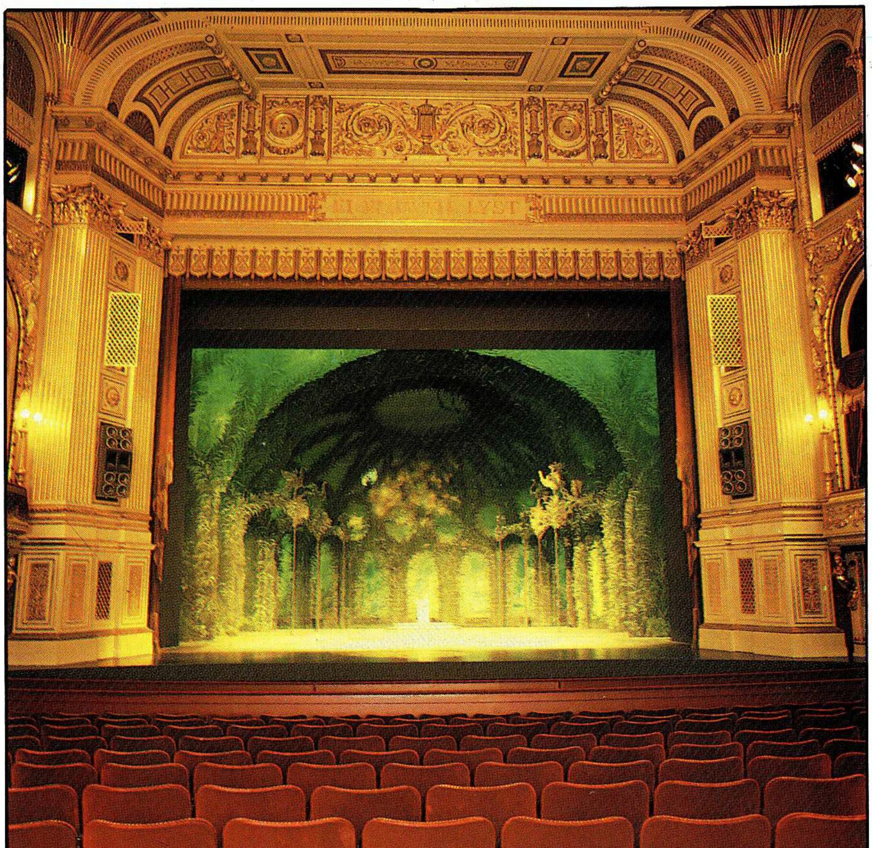


A 4301B monitor loudspeaker is mounted in the chandelier for the "Voice of God" effect.



View of the auditorium from the rear of the main floor. The loudspeakers are in operating position. The stage is set for Mozart's "Die Zauberflote" ("The Magic Flute").

A sound system requested

The first priority of the theater's sound engineers in connection with the rebuilding was to acquire a new sound reinforcement system. There is no long tradition for using loudspeakers in the Royal Danish Theatre. With the recent introduction of modern dance, however, many ballets are performed with prerecorded music—music that is often impossible to perform *live.*

The engineers also needed a sound reinforcement system that would be able to reproduce taped music simultaneously with an orchestra without making the audience aware that tape was in use, for example in the Gyorgy Ligeti score for John Neumeier's ballet "A Midsummer Night's Dream," where the orchestra and the sound engineer alternately play the music. For opera, it is not unusual to use prerecorded parts now: in Alban Berg's "Wozzeck," the sound engineer imitates *Whistling through fingers* in time with the music, and for "Boris Gudonov," the church bells of the Kremlin are taped, as are Lohengrin's bells in Wagner's "Parsifal."

The sound engineer has prerecorded parts ready on a tape recorder, and during the performance he must follow the music score just as the musician in the orchestra pit does. His score contains precise timing of his tapes and/or notations for controlling amplification, which may be solo, choir or special instrument reinforcement.

Additionally, the system is also used with wireless microphones during musical comedies and light operas. The sound engineer is in a control room where he can see the conductor on a video monitor. House microphones and two monitor loudspeakers make it possible for the sound engineer to hear the sound in the auditorium.

As noted above, the system is used for a large variety of purposes. In ballet, the styles range from classical to modern music. For operas, the sound sequences may also vary stylistically, which makes for heavy demands on the sound reinforcement system, both for high quality and high sound pressure level. These requirements demanded a system capable of providing broadly dispersed, realistic sound levels over a wide frequency range.

Stage sound reinforcement

There is also a separate sound reinforcement system on the stage. It is primarily used for sound effects, but it also monitors the orchestra sound to the stage. In reproducing the orchestra sound for the artists on the stage, the rhythmic precision is improved, because the delay of the direct sound from the orchestra pit is subdued. This is of particular significance to musicians and/or choir singers to the rear of the stage.

The auditorium system

The principal requirements for the house system include: maximum SPL of 110dB with reasonable transient headroom, frequency range from 20Hz to 20kHz, and smooth sound coverage all over the auditorium, combined with low distortion. The solution was a 4-way system consisting of a subwoofer (20Hz-80Hz), dynamic speakers for midrange (80Hz-1,500Hz), and horn/compression drivers for high frequencies (1.5Hz-7.5kHz) and ultra-high frequencies (7.5kHz-20kHz). Figure 1 is a block diagram of the system.

Minimizing resonance phenomena and distortion was one of the prime considerations when selecting transducer types (horn/compression drivers vs. cone transducers) and crossover points.

A special double-tuned, bass-reflex subwoofer cabinet design results in a minimum of cabinet resonances and lower harmonic distortion, because the vents function as low-pass filters. Even the best compression drivers generate audible harmonic distortion when heavily driven, so the system uses cone transducers up to a crossover frequency of 1.5kHz.

The auditorium has a surface area of 3,036m^2 (30,000ft^2) and a volume of 6,075m^3 (218,000ft^3). In the frequency range from 80Hz to 20kHz, the stage and the auditorium may be considered as two acoustically separate worlds. However, when calculating the sound pressure under 80Hz in the auditorium, you must take the stage into consideration. The dimensions of the stage are 20m long × 22m wide × 27.5m high (60'× 66'× 91'), and the volume is 12,100m^3 (360,000 ft^3).

Because the subwoofer system is placed near the forestage, no acoustic support from the stage area could be expected; reverberation measurements carried out on the floor level with a drawn curtain, side scenes, and without an audience bore this out.

When the construction of the auditorium is correlated to the relatively short reverberation time in the hall (approximately 1.4 seconds in the 2kHz band), the result is a fairly high degree of intelligibility for plays, but somewhat less than optimum reverberation for music.

Visual limitations

The old stage of the Royal Theatre is listed as a national historic site and the visual aspects of the architecture could not be altered, so optimum acoustic placement of the house systems was totally out of the question.

After we consulted with the theater's architect, small rooms on either side of the proscenium, next to the Royal Box and the court ladies' box, respectively, were assigned as loudspeaker areas. Each room has an opening to the auditorium. The openings measure 160cm × 65cm (63"× 25.5") and are covered with lattice grilles. The side systems had to be hidden behind the grilles when not in use. The grilles can be opened, allowing the side systems to move into view during use, but the systems cannot impede audience sight lines, and, thus, are only allowed to protrude 50cm (19¾ inches) from the wall. The theater's sound engineering department was well aware of these limitations, but the architect has a great deal of power.

The *enforced* loudspeaker placement makes normal left-right coverage impossible—the only practical solution is cross coverage, that is, the left speaker covers the right side of the auditorium

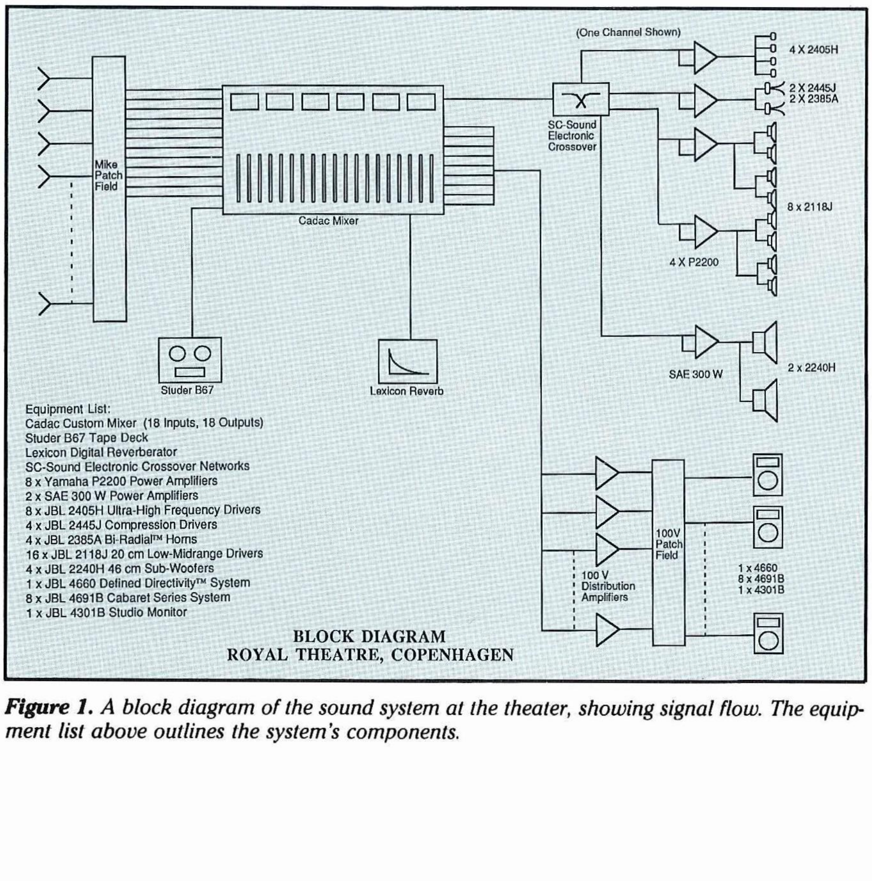


Figure 1. *A block diagram of the sound system at the theater, showing signal flow. The equipment list above outlines the system's components.*

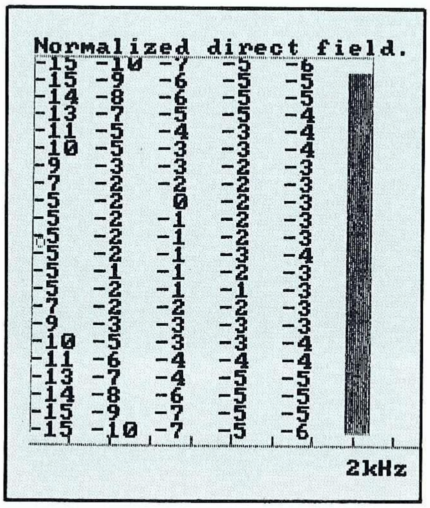


Figure 2. *CADP output showing the main seating area losses at 2kHz. Notice the uniform coverage the system provides.*

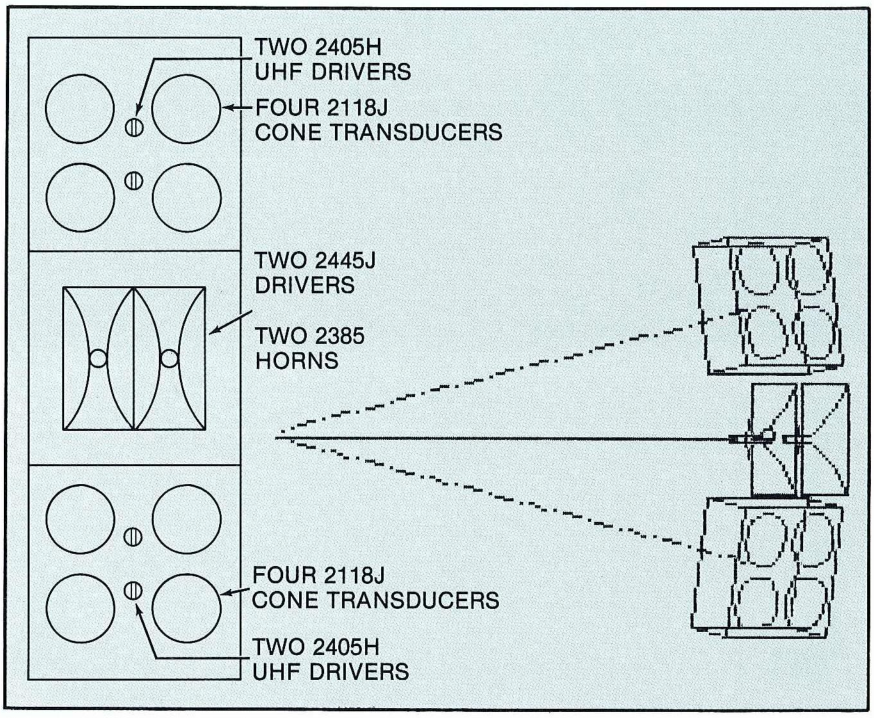


Figure 3. *The two high midrange speaker systems (top and bottom) are angled around two Flat Front Bi-Radial horns with compression drivers. The computer simulation to the right shows a side view of the cluster system. Notice how the cluster is angled.*

and the right speaker covers the left side. Because of this, it was feared that the system would be lacking in stereophonic panorama and that there would be no directional comprehension. Actually, the system provides adequate directionality.

To achieve smooth coverage of all seats, this cross coverage results in a requirement for precise limits of the directional pattern of the speakers throughout the frequency range. This parameter was of prime importance in designing the system.

CADP used

When the system was designed, our Central Array Design Program (CADP) computer program was used. For this task, the program has been a great help, especially when aiming the system in the auditorium. The auditorium consists of a floor level and four balconies.

CADP allowed the acoustical characteristics of the theater's stage and audience area and the layout of the seating planes as well as the loudspeaker arrays to be modeled. Because of this, the house systems could be assembled and aimed for maximum sound in the seating area, for minimum sound outside of the area, and for minimum comb filter interferences from the multiple drivers. Figure 2 shows the main seating area losses at 2kHz as predicted by CADP.

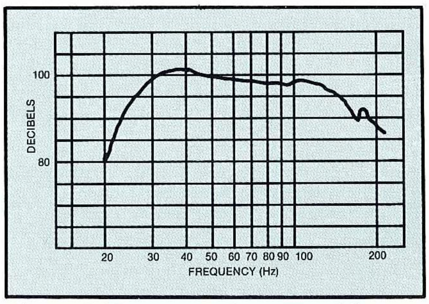


Figure 5. *The measured response of the completed system.*

Measurements in the house of the installed systems have borne out these predictions. Additionally, the main and side stage monitor systems could be properly placed and aimed for maximum stage coverage with minimum acoustic leakage into the auditorium.

High midrange

Each of the two systems, shown in Figure 3, contain eight 2118J 200mm (8 inch) cone transducers, in two groups of four. Each transducer is mounted in a sealed enclosure of 80 liters (2.8 ft^3). The two groups have been angled around two 2385 Flat Front Bi-Radial horns with 2445J compression drivers. The spacing between the individual cone drivers in each group has been calculated to form a *double column speaker*, giving the desired limited directional pattern in the frequency range of 80Hz-1,500Hz. The upper cutoff-frequency of these groups has been chosen at 1,500Hz to avoid lobing effects. These groups provide most of the energy from the side systems.

The two 2385 horns have been mounted vertically next to each other,

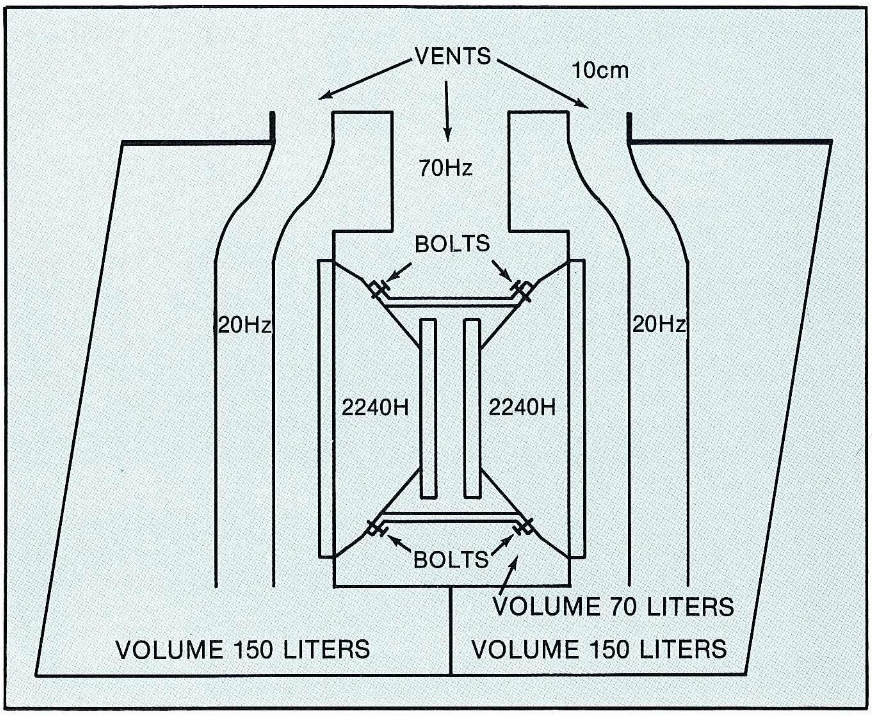


Figure 4. *Detailed drawing of the subwoofer system.*

between the two groups of four 2118J, 8-inch transducers. The 2385 horns have a nominal pattern (−6dB) of 60°×40° when mounted horizontally. With two horns placed with adjacent mouths, the horns maintain their vertical pattern down to 1kHz, so that with a crossover frequency of 1.5kHz, the pattern control is well maintained. In order to meet the directional pattern requirements of this theater, the horns are oriented with their wider dispersion angle vertical rather than horizontal.

Eight 2405H ultra-high frequency drivers are crossed over at 7.5kHz and extend the system response to 20kHz. The drivers are mounted in pairs, vertically aligned between each group of four 2118s. (See Figure 3.)

Low frequency

A new subwoofer system was specifically designed for the "Old Stage" of the Royal Theatre. (See Figure 4.) Initially, two conventional bass reflex subwoofers were placed in the orchestra pit. These worked satisfactorily, but were inconvenient for the musicians, who did not have much room in the orchestra pit. It was often necessary to remove these speakers when larger ensembles performed.

The theater sound engineers wanted the subwoofer system permanently installed, but space was, once again, a serious problem. The only possible spots to install the system were in two small rooms on either side of the proscenium, two floors above the side systems. Each room has an opening into the auditorium of 65cmx30cm (25½"x11¾"), covered by a latticework grille. A new subwoofer design had to be developed to fit into the available space.

The system solution required a new design concept that loads both sides of the cone with resonant circuits (bass reflex), using different vent tuning frequencies for each side of the cone. The vents lead into the auditorium through openings, and the grilles are opened in order to prevent any air noise caused by the high air velocity in the vents.

It was necessary to develop a computer program in order to analyze this subwoofer principle. (See Figure 5.)

Each of the two subwoofers consists of two 2240H low-frequency transducers, with their magnets bolted together, working in push/pull motion. From an acoustic point of view, the loading of the two transducers are identical. This identical loading results in identical current, which then results in two identical forces. As a result of the push/pull configuration, the mechanical forces transmitted by the speaker frames cancel out, and the resulting force on the cabinet structure is caused primarily by the acoustic pressure.

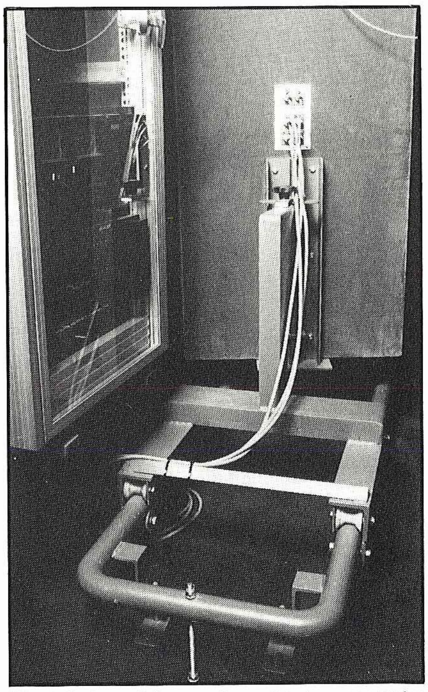
Stage monitoring

The monitor system on the stage uses a 4660 directivity system mounted at 9m (30 feet) height, directly above the stage opening. This placement allows the 4660's asymmetric horn to cover a rectangular area on the stage. In addition to the 4660, eight 4691 Cabaret systems are mounted along the stage side walls.

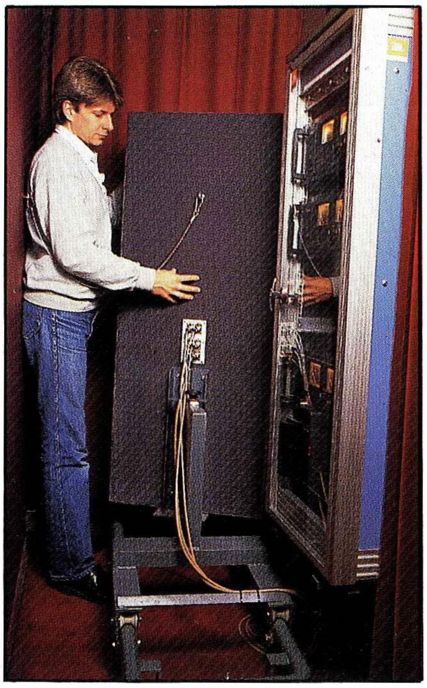
All speakers on the stage are powered through 100V systems. The need for sound reinforcement on the stage varies a great deal, depending on the particular performance (opera, plays, etc.), so for that reason, each stage speaker system is wired through a patchbay that enables the sound engineer to quickly connect and disconnect each individual speaker as needed. Heavy-duty transformers with massive cores allow the stage

Two 4401 monitor loudspeakers are used in the control room because the first balcony blocks the clusters.

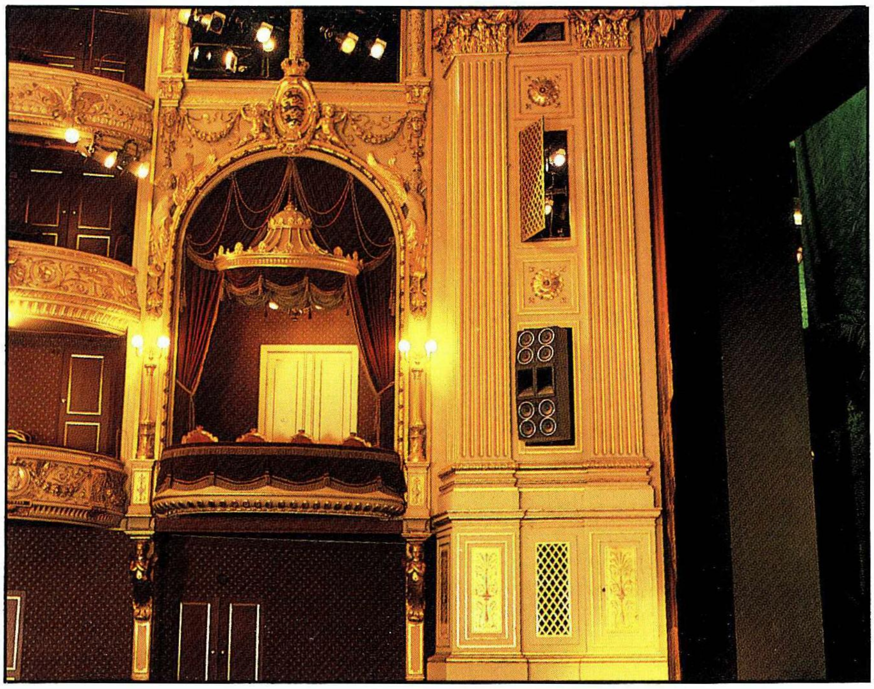
Eight 4691B Cabaret series loudspeakers supply side-monitor foldback to the stage.



The tubular, sliding rack used to transport the cluster.



Rear view of a mid-high cluster before it is moved into its operating position. The amplifier rack is to the right. The 6'4" tall (1.92m) engineer standing next to the cluster indicates its size.



The Royal Box is to the left of one of the speaker systems. The subwoofer enclosures are mounted behind the latticework grilles to the right. The grille at the top is open to prevent air noise from the subwoofer.

speakers to reproduce low frequencies at high power levels with insignificant amounts of added distortion.

The system was installed and balanced using only the level controls on the crossover networks and power amplifiers. The response in the first row of the first balcony was measured prior to the installation of the new subwoofer system. This response was judged to be smooth enough, with enough gain before feedback using live microphones, that room equalization was unnecessary and not installed.

The system premiered during the Royal Danish Ballet's first performance of Alvin Ailey's ballet *Caverna Magica*, using music from an Andreas Vollenweider compact disc. Reaction to the new installation has been extremely positive. The theater's engineers are very pleased with their new tool, and the improved sound quality and coverage has been enthusiastically received by audiences and performers alike. S&VC