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CARMEN® in the Norwich Theatre Royal, UK

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Since 1999 the CARMEN[®] system has been installed in several halls in Europe. The last installation took place in November 2007 at the Norwich Theatre Royal. This classical stage venue has been completely refurbished to become a multipurpose hall with 1280 seats and a single very deep balcony. To fulfil the different acoustic requirements for each performance type (from speech drama to symphonic music) it was decided to install an electroacoustic Reverberation Enhancement System. CARMEN[®] is a regenerative one which is based upon the virtual wall principle. It can increase the Reverberation Time (RT) of a hall up to 100% and adapt the acoustics to each performance.

The installed system has been tuned with 6 configurations: Theatre, Chamber Music, Opera, Concerto, Symphony, and Chorus. The RT of the empty hall now ranges from 1.1s without CARMEN[®] to 2.2s in the Chorus preset.

A brief description of the CARMEN[®] principle will be presented first. Then the tuning of the different configurations in the hall will be described. Empty hall measurements have been done and the measured acoustic criteria will be analysed. The deep balcony of the Norwich Theatre Royal separates it into two slightly coupled volumes. This particularity will be discussed.

1 Introduction

The reopening of the Norwich Theatre Royal took place in November 2007 after it had been refurbished by Tim Foster Architects to become a multipurpose hall with 1280 seats. The new hall has a single very deep balcony which overhangs the rear stalls (see Fig.1). The aim was to use the Theatre Royal for a wide range of musical events such as opera, ballets, orchestra performances, theatre, as well as a variety of amplified music performances (jazz, musicals, etc.).

The acoustic design has been carried out by the acoustic consultant Paul Gillieron. Acoustic modelling of the theatre has shown that the passive reverberation time (RT) of the room is around 1.0 s occupied at mid-frequency. The computer simulation of several room acoustic criteria has also shown that the theatre is appropriate for speech and amplified music performances. Indeed, these results are considered dry for opera, with poor listening conditions under the balcony. The theatre does not have good acoustics for orchestral and chamber music, which require a longer RT. In order to reach a more reverberant acoustic for performances such as opera or symphony it was decided to install a reverberation enhancement system. CARMEN[®] was chosen for the Theatre Royal.



Fig.1 View of the new Theatre Royal from the stage

2 The CARMEN[®] principle

Designed for halls with 800 to 2500 seats, CARMEN[®] is a regenerative system which improves the RT in halls while preserving the original architecture. It is based upon the Virtual Wall principle [1] which preserves the natural sound propagation in the hall. Each virtual wall created with CARMEN[®] is composed of several independent cells which are each composed of a microphone, a loudspeaker and a Digital Signal Processing unit (see Fig.2). The microphones are normally placed close to the corresponding loudspeaker to have the characteristic for a “locally reacting system” [2].

Each cell is made of :

- a loudspeaker
- an electronic processing unit
- a microphone insensitive to the acoustic radiation of the loudspeaker

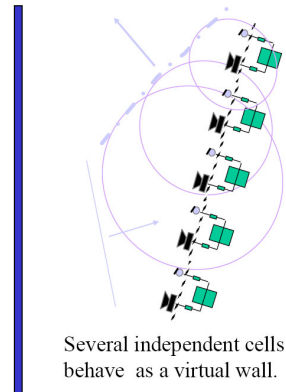
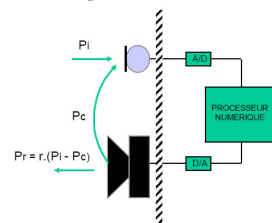


Fig.2 The Virtual Wall Principle

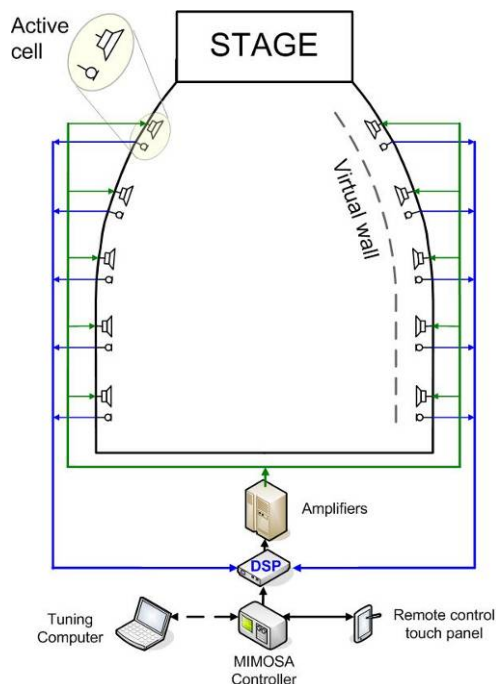


Fig.3 CARMEN® Block Diagram

The electronic architecture shown in Fig.3 allows an increase of the natural RT of 100% [3]. In the Theatre Royal, 27 cells are spread over the entire hall to assure good sound homogeneity and to form 2 virtual walls and a virtual ceiling for both the stalls and the balcony.

Once CARMEN® is installed and tuned the user has only to turn on the system and to choose the appropriate preset acoustic configurations for the performance.

3 CARMEN® installation in the Theatre Royal

The new Norwich Theatre Royal hosts performances from speech drama to chorus recital. These various types of performances require different RT (from about 1 second for speech drama, to more than 2 seconds for chorus). For this reason, six configurations have been chosen during the design phase of the project. These configurations correspond to speech drama, chamber music, opera, concerto, symphony and chorus. The tuning has been done just before the reopening once all building works had been finished.

The Speech Drama configuration is an optional configuration of the CARMEN® system which is only available if forestage microphones have been installed. The Theatre Royal is equipped with these forestage microphones which captures the sound on stage so as to reinforce voices in the theatre.

A brief description of each preset is given in Table 1.

Preset	Description	Use
0	System off: RT = 1.1 s	Conference, Amplified Music
1	RT almost unchanged: 1.1 s <i>Voice reinforcement</i>	Speech Drama
2	Medium RT increase: 1.6 s <i>Reinforced lateral effect</i>	Chamber Music, Recitals with soloists
3	Medium RT increase: 1.7 s <i>Voice reinforcement</i>	Opera, Singer Recital
4	Large RT increase: 1.8 s <i>Homogeneous effect</i>	Concerto (soloist with orchestra)
5	Large RT increase: 2.0 s <i>Homogeneous effect</i>	Romantic or Classical Symphony
6	Very large RT increase: 2.2 s <i>Enhanced bass response</i>	Chorus

Table 1 Acoustic configurations of CARMEN® in the Theatre Royal

4 Final measurements

The passive acoustics of the hall (system off) and the 6 configurations of the active acoustics have been measured. The auditorium was empty, and chairs and curtains were installed on stage during the measurements.

In order to ensure good measurement coverage, 27 receiver points have been spread over the hall with 14 located in the stalls and 13 located in the balcony (see Fig.4).

Impulse response measurements have been made using the MLS Hadamard technique. The source used was an amplified loudspeaker Genelec placed in the centre of the stage at a height of 1m and 3m from the front edge. An omnidirectional microphone Sennheiser MKH80 has been placed at each measurement point. The calculation of the criteria and their processing has been done thanks to a specialised computer program.

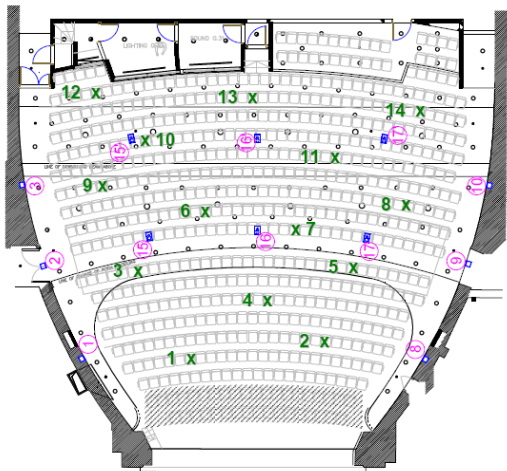
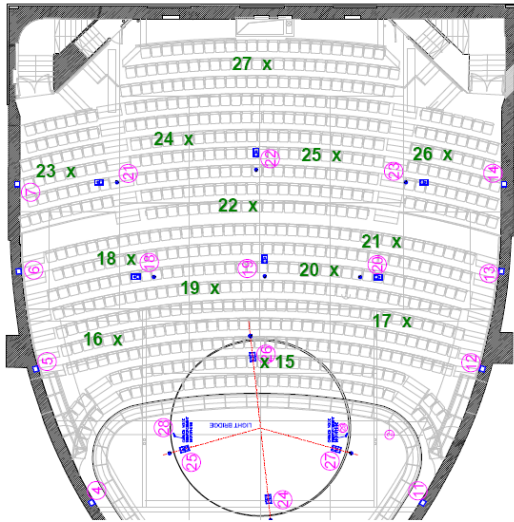


Fig.4 Measurement points in green, with the 27 installed CARMEN® cells in blue. Balcony plan above and stalls plan below

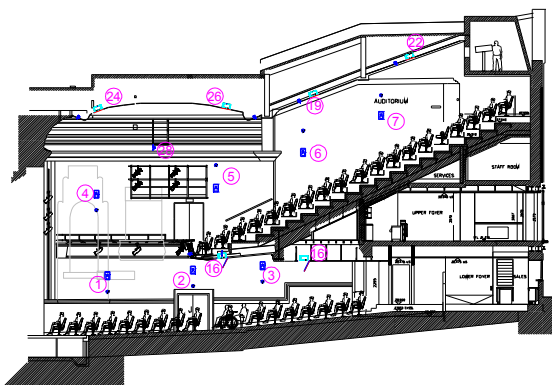


Fig.5 Cross-section view with CARMEN® cells in blue

5 Analysis of measurements

5.1 Theatre criteria

In this section the preliminary analysis of the effect of CARMEN® on the acoustic field in the Theatre Royal is presented. It shows the significant mean acoustic criteria measured in the hall. Fig. 6 shows the echogram when the system is off and in 4 other configurations. The smooth decay shows a very homogeneous sound distribution.

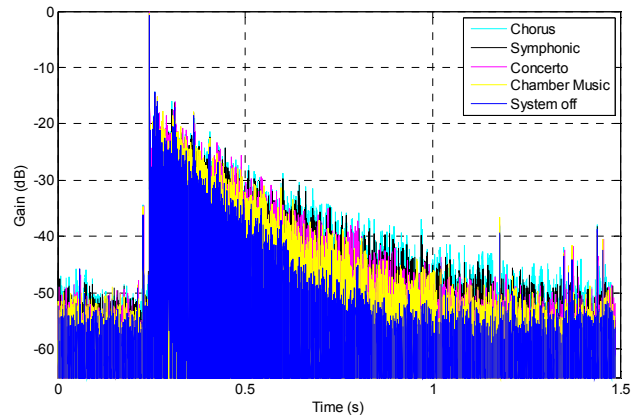


Fig.6 Normalized echograms with and without CARMEN® at the receiver position n°20

The first discussed criterion is the reverberation time RT30 (see Fig.7). The RT30 is increased by 100% at 500 Hz from the system being off (1.1s) to the Chorus configuration (2.2s). We notice that low frequencies have been slightly increased for the Symphonic and Chorus configuration so as to create an ample and warm sound.

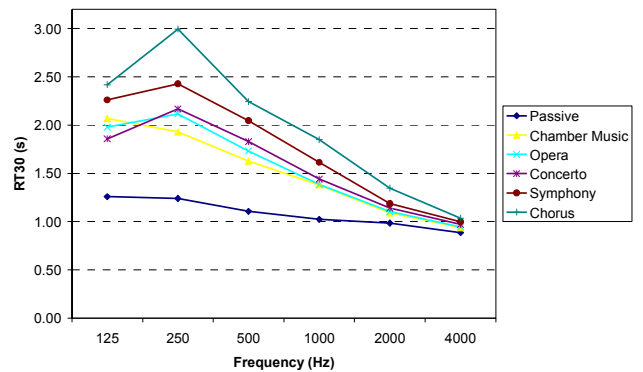


Fig.7 Mean Reverberation Time 30

When the system is turned off, Early Decay Time (EDT) is about 10% below the RT30 measured under the same conditions. With an EDT of 1s a rather short impression of the reverberance during music performances is expected.

EDT is slightly increased more than RT30 at all frequencies when the system is turned on as shown in Fig.8 (respectively 110% and 100% in Chorus mode at 500Hz). This ensures a richer echogram (see Fig.6) and a good impression by the listeners of the reverberance.

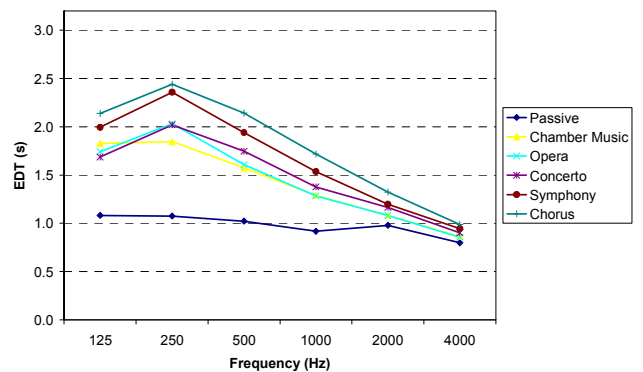


Fig.8 Mean Early Decay Time

The clarity C80 is a criterion dedicated to music. Without the system the clarity in the Theatre Royal is very high with 4.6 dB at 500 Hz (see Fig.9). This is mostly related to the lack of reverberance in the theatre. When CARMEN® is switched on the clarity remains good although a high reverberance is measured in the theatre. The clarity C80 is over -2 dB at 500 Hz for all configurations, which is appropriate for music performances.

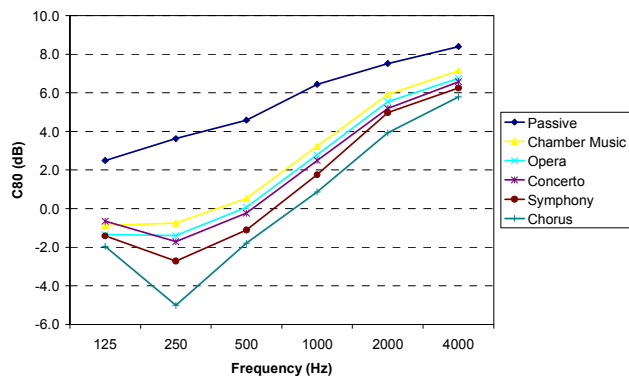


Fig.9 Mean Clarity

5.2 Volume under the balcony

The volume of the hall can be divided in three main volumes (see Fig.5):

- front stalls
- rear stalls under the balcony
- above the balcony

The acoustic analysis has focused on the under balcony volume because its narrow volume is less coupled to the rest of the hall. Comparison of the measurement results with the other 2 volumes have been done for the SPL and a brief comment is made to evaluate the CARMEN® effect on the different parts of the hall.

Without the system RT30 at 500 Hz has been measured at 1.1s for the entire hall and 1.2s for the volume under the balcony (see Fig. 10). The volume under the balcony is more reverberant probably because of the control rooms window at the rear wall which is less absorbent, and because of small flutter echoes which extends the decay time.

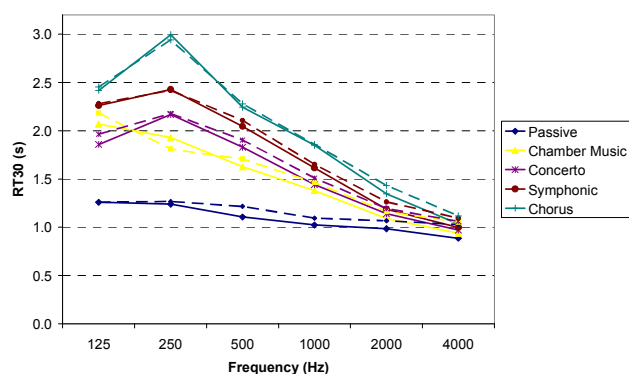


Fig.10 Mean RT30 in the theatre (continuous line) and mean RT30 under the balcony (dotted line, measurement position 6 to 14)

Without the system the clarity under the balcony is higher than in the entire theatre (1 kHz and 2 kHz octave band > 8 dB). With CARMEN® the clarity under the balcony becomes similar to the clarity of the entire theatre as shown in Fig.11.

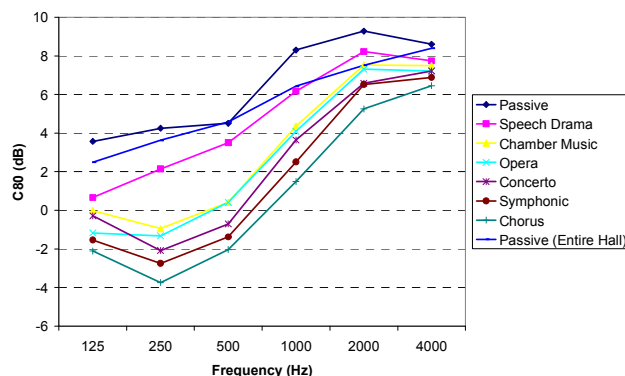


Fig.11 Clarity under the balcony (measurement position 6 to 14) and mean C80 in the hall

The difference of Sound Pressure Level (SPL) between the front orchestra stalls and under the balcony with the system off is 2.1dB (see Fig. 12). These results show that the use of CARMEN® reduces this difference to 1.3dB for Speech drama and to 1.5dB in the other configurations.

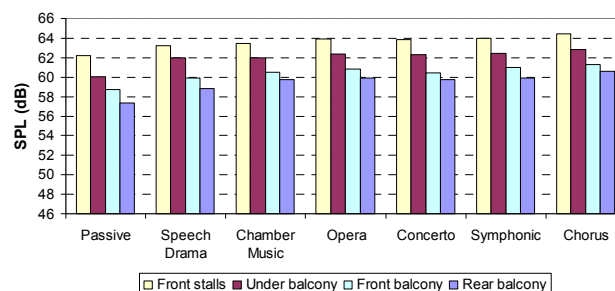


Fig.12 Sound Pressure Level at 1 kHz in the hall with $SPL_{source} = 81.1$ dB at 1m

When the system is off the difference between the front of the balcony and the rear of the balcony is about 1.4 dB. This difference is less than 0.9 dB when the system is turned on.

Conclusion

The CARMEN® system has been installed to fulfil the variety of performances hosted by the newly refurbished Norwich Theatre Royal. The very deep balcony presented in this theatre creates a rather decoupled volume for speech drama as well as for classical music shows in passive acoustic configuration. The system has been tuned to increase RT in the theatre so as to host different performances from chamber music to chorus recital with orchestra ensemble and also to enhance the acoustics of the area under the balcony and at the rear of the balcony.

The effects of the CARMEN® system on the room acoustic have been evaluated with some measured criteria. It has been shown that the originally rather decoupled volume under balcony is now acoustically integrated into the theatre. The acoustics of this multi-purpose theatre is now

very homogeneous, especially in the rear balcony seats located far from the stage.

Acknowledgments

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