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# DIFFERENT SOLUTIONS FOR THE ELECTRO ACOUSTIC DIFFUSION SYSTEM IN SAN LORENZO CATHEDRAL IN PERUGIA

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## Abstract

San Lorenzo Cathedral in Perugia (Italy) is the most important religious building of the town; its particular architectural structure causes a bad acoustic quality. The aim of the present paper is the determination of the current acoustic situation and the comparison of seven different electro-acoustic systems proposed by different firms; carried out by means of several measurement campaigns.

## INTRODUCTION

Acoustic features in a large closed space are extremely important when a sound signal have to reach all areas to give an acoustic comfort sensation to the occupants.

Frequently, a good electro-diffusion system solves the problems assuring a good speech transmission without needing correction.

In the present paper the case of a building with particular historical value like an ancient church is examined. A previous study evaluated the current acoustic situation of San Lorenzo Cathedral in Perugia: results were compared to the ones obtained with several electro-diffusion facilities proposed by different firms. Measurement sessions were carried out to collect the main acoustic parameters, in compliance with ISO 3382; then, in order to help the choice of the best electro-diffusion system, a speech transmission test was carried out, in compliance with ISO TR 4870, which proposes a method to evaluate a subjective judgement about speech intelligibility. A technical-economic analysis was carried out to support the final

decision: the number of loudspeakers, the assistance, the warranty are examples of parameters considered in this section. Finally, after the installation of the new system in the Cathedral, another measurement session was carried out, in order to verify the correspondence between the demo version and the final configuration.

## THE CURRENT ACOUSTIC SITUATION

### San Lorenzo Cathedral

The 22nd of March 1300 Priors, art Camerlingos and people delegates established to start the building of the Cathedral consecrated to Saints Lorenzo and Ercolano. The planner was monk Bevignate, who conceived an *Hallenkirche* building where the main nave and the two side aisles have the same height of 24.90 m.

Only in fifteenth century the church was finished, assuming the actual appearance. The interior of the building gives an idea of wideness, thanks to the nave ratio and the ten octagonal columns; a light and dark effect is assured by double lancet windows. The strong gothic base is relieved by the Eighteenth style: paints, shiny stuccos, gilding particulars, and a lot of marbles; the vaults are painted by the most important Italian masters.

### The first measurement session and the current situation

The aim of the first measurement campaign was to define the acoustic quality of the church. In order to estimate the reverberation time, a dodecahedral source and a random incidence microphone were used: the source was set in two position, one in front of the high altar and the other at the end of the nave; the microphone was set in four positions,as shown in figure 1 (Left). A Symphonie system by 01 dB, used in all measurements, generates and register an MLS signal for all the eight positions; during the measurement session the church was empty.

Figure 1 (Right) shows the mean value of reverberation time vs. frequencies.

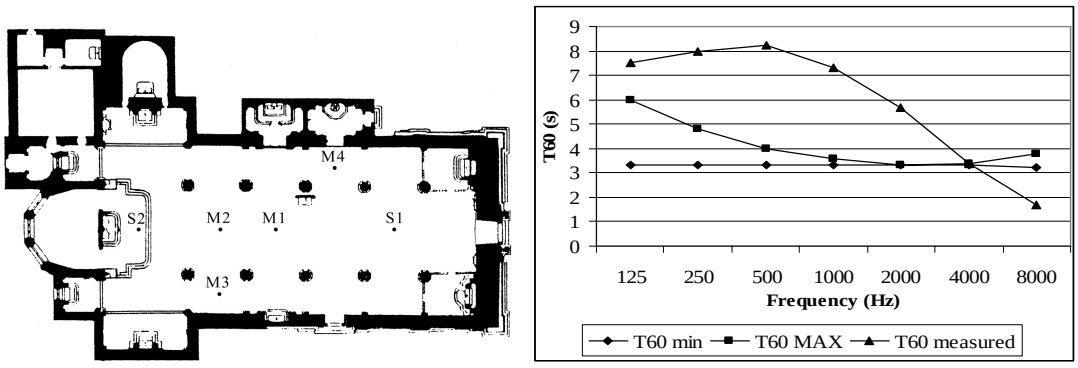


*Figure 1 – (Left) San Lorenzo Cathedral's plan – Source (S1, S2) and microphone positions (M1 to M4).(Right) Reverberation Time measured and optimal range for the church*

For low frequencies, until 2 kHz, values are very high, four seconds more than the optimal range; at 4 kHz, the mean value of $T_{60}$ is comparable with the optimal value; at 8 kHz the value is lower of 1,5 seconds than optimal range. In a second phase of the measurement campaign the old electro-diffusion system with 42 loudspeakers was used. Measurement positions were 13, covering the area normally occupied by the congregation; the signal was MLS again.

Table 1 shows the results obtained in this second phase of the campaign for STI and RaSTI in the 13 positions, while the last column contains the mean values for the Cathedral. Comparing data to the optimal range found in the Literature [5], global classes of intelligibility poor or fair were found.

*Table 1 – STI and RaSTI mean values for each position*

| **POS** | **1** | **2** | **3** | **4** | **5** | **6** | **7** | **8** | **9** | **10** | **11** | **12** | **13** | **Mean** |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **STI** | 0,35 | 0,37 | 0,45 | 0,34 | 0,41 | 0,41 | 0,41 | 0,41 | 0,44 | 0,42 | 0,41 | 0,39 | 0,42 | 0,40 |
| **RASTI** | 0,37 | 0,34 | 0,50 | 0,33 | 0,43 | 0,36 | 0,40 | 0,38 | 0,45 | 0,43 | 0,42 | 0,40 | 0,45 | 0,40 |

Mean values of $D_{50}$ index (Table 2) for each frequency are far from 50%, the minimum value for a correct speech definition, except for the frequency of 8 kHz.

*Table 2 – $D_{50}$ index, mean values vs. frequencies*

| **Frequency (Hz)** | **125** | **250** | **500** | **1000** | **2000** | **4000** | **8000** |
|---|---|---|---|---|---|---|---|
| **$D_{50}$ (%)** | 15 | 12 | 22 | 36 | 35 | 43 | 61 |

## COMPARISON OF DIFFERENT ELECTRO-ACOUSTIC SYSTEMS

The Archbishop of Perugia decided to change the old electro-diffusion system, in order to improve the acoustic quality of the Cathedral. The electro-acoustic performances of seven different systems proposed by different firms were evaluated. Each firm installed a demo version of the proposed solution, trying to reproduce the real situation after the installation. Measurements for each session were carried out in the same 13 positions of the receiver considered in the actual state characterization.

Instruments were directly connected to the diffusion system's endings, in order to bypass filters and to obtain a flat configuration; moreover, two control positions were chosen in the church to set the power level of each system at 65 dB(A), to uniform the tests and to guarantee the repeatability of the measurement session.

After instrumental tests, a speech intelligibility test (ALCons), in compliance with ISO TR 4870, was carried out in the Cathedral to obtain a subjective judgement about sound intelligibility.

By now, the seven firms are indicated with numbers from 1 to 7.

## Measurement's results

No significant differences were measured in the reverberation time, because it is strictly mainly due to the architectural features of the Cathedral.

Instead, figure 3 shows STI values obtained in the 13 positions with the seven different systems; the best results were obtained for Firm 3, with a mean value of 0,53, Firm 6, with a mean value of 0,52, Firm 5 and 7 with 0,50; all these values define an intelligibility class of quite good in the STI scale. RaSTI index values are quite similar to the STI ones: in fact, they show the best values for Firm 6 (0,50) and then for Firm 2, 3, 7, all with 0,49.

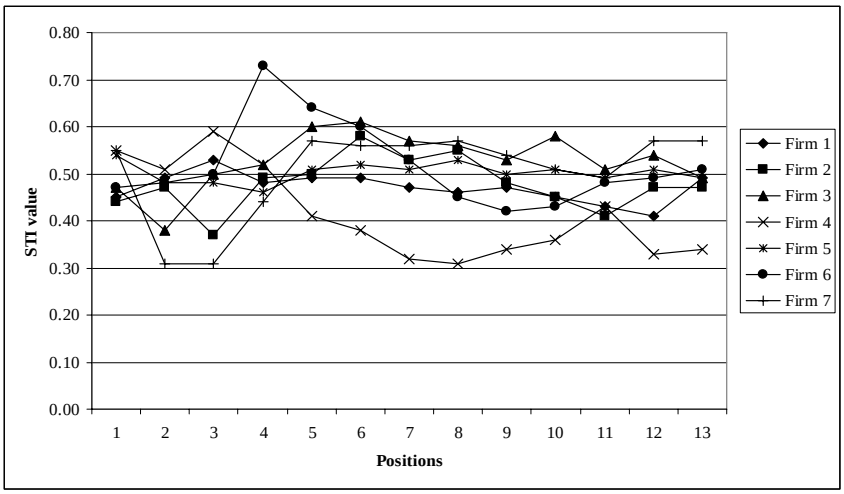


*Figure 3 – Measured STI values for the seven different electro-acoustic systems*

Figure 4 shows the results for $D_{50}$: Firm 6 obtained the best mean percentages, with 54 %, Firm 3 had 52 % and Firm 7 49 %.

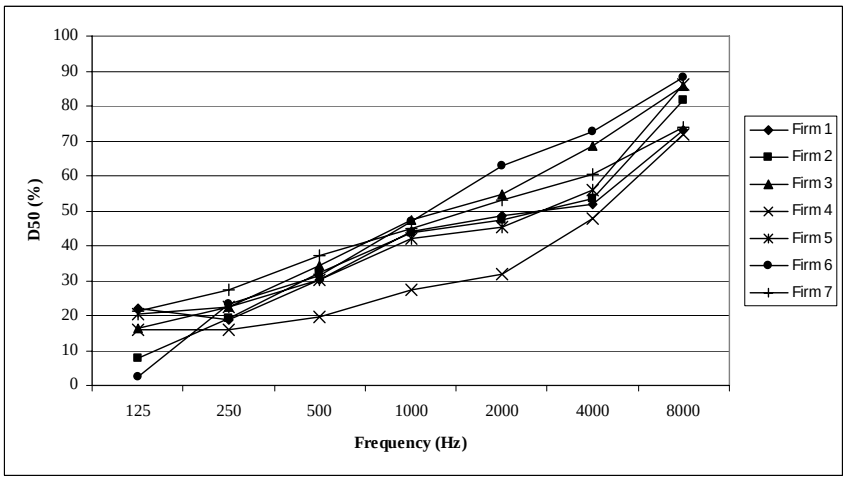


*Figure 4 – Measured $D_{50}$ values for the seven different electro-acoustic systems*

**Speech intelligibility test**

The ISO standard TR 4870 defines a methodology to realize and evaluate a speech intelligibility subjective judgement by read and comprehension of a list of words (ALCons test).

A closed set was chosen; lists are made of 50 words changing the first or the second syllable; two readers, a man and a woman, read from two positions (high altar and ambo), while nine listeners had three options between the real one.

The standard provides the equation to obtain the percentage of speech intelligibility:

$$I(\%) = \frac{100}{T}\left(R - \frac{W}{N-1}\right) \tag{1}$$

where

T = total number of words; N = number of options for the listeners, N ≥ 2; R = (right) number of right answers; W = (wrong) number of wrong answers.

Figure 5 shows results of ALCons test: the percentage are all over 90%, so speech intelligibility global level is good; values are particularly high for Firms 1 and 3, values are excellent for Firms 6 and 7.

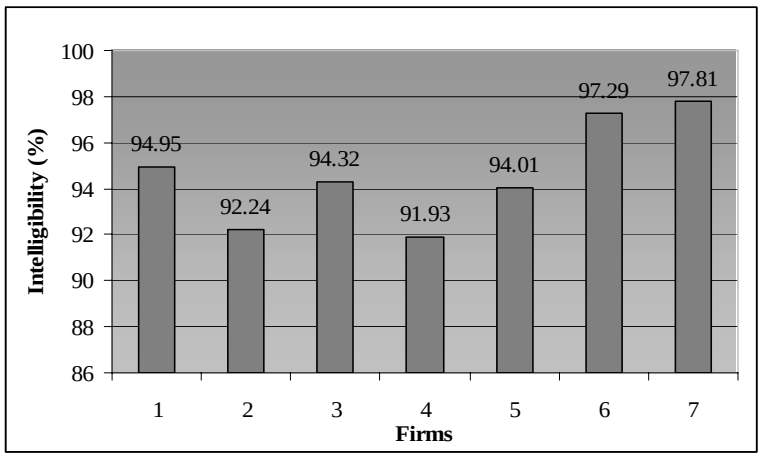


*Figure 5 – ALCons test results for the seven different firms*

## TECHNICAL-ECONOMIC ANALYSIS

The final decision on the best solution between the seven different electro-acoustic systems for San Lorenzo Cathedral evalueted other parameters besides instrumental and ALCons results. For the sake of brevity, only the choosing criteria and the parameters involved in this comparison are reported. Very important were the technologies and the loudspeakers characteristics: active or passive arrays, waves

emission type, power and weight; another element considered was the number of loudspeakers: a small number is to prefer, respecting the historical value of the church. Amplifier, mixer and data management are other technical elements studied; furthermore, it was important to check the devices warranty and the assistance.

Finally, the cost was the last point observed. Crossing all this data, the system proposed by Firm 6 was the best arrangement: the plan is composed by 16 loudspeakers, with cylindrical wave emission; each array has a power of 300 Watt, 15 degrees of vertical opening, 160 degrees of horizontal opening; the mixer and the amplifier are totally digital and the system is very simple and useful.

## POST OPERAM MEASUREMENT SESSION

Post operam measurement campaign showed a very good agreement between results obtained with the demo version and those obtained with the final electro diffusion system installed.

Figure 6 shows mean values of $T_{60}$ and $D_{50}$ of demo and final configurations, compared with optimal range.

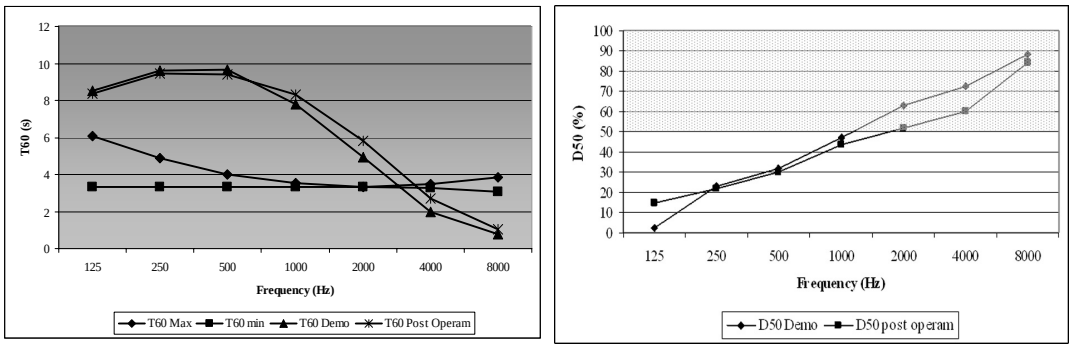


*Figure 6 – Post operam results: $T_{60}$ (left) and $D_{50}$ (right) mean values and optimal range*

Figure 7 shows a comparison between the demo and final version of electro diffusion system for STI (left) and RaSTI (right).

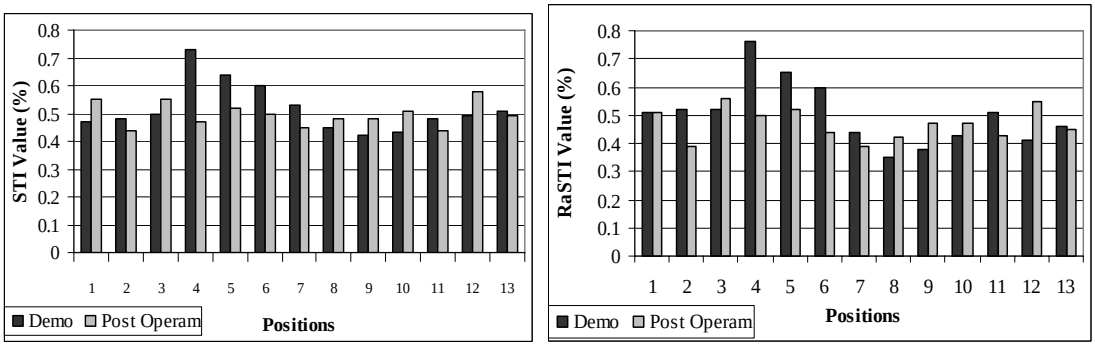


*Figure 7 – Post operam results: STI (left) and RaSTI (right) mean values for each position*

Post operam measurement session showed an improvement of the quality for speech transmission. Except for positions 4, 5, 6 and 7, where the demo version had best results, the overall intelligibility class is fair. Similarly, the values of RaSTI index have the same trend.

Finally, figure 8 shows the measured Acoustic Pression Level (Leq) in the Cathedral after the installation of new loudspeakers system. Differences between demo and final version of the electro diffusion system are meaningful: all the values measured in the final situation were about 65 dB(A), with a maximum of 67 dB(A), while in the demo version the values varied from 53 to 63 dB(A). The final situation reveals furthermore a perfect spatial distribution of the sound, with no acoustic shadow zones.

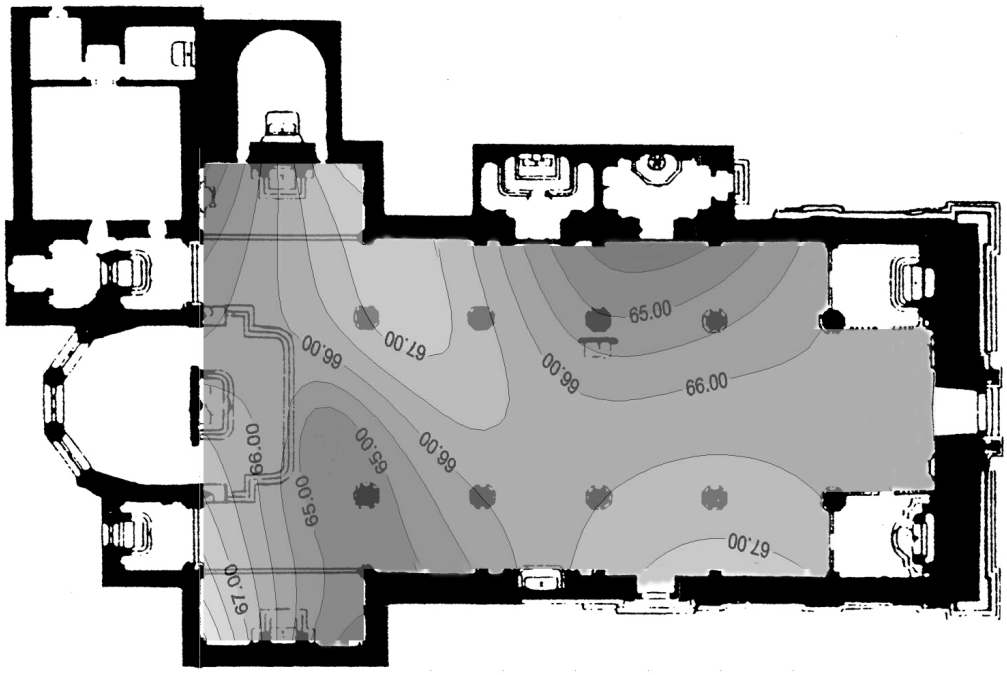


*Figure 8 – Spatial distribution of Leq Levels in post operam measurement session*

## CONCLUSIONS

San Lorenzo Cathedral is the most important religious building in Perugia (Italy). The particular architectural structure of the church and the height naves are responsible of a bad acoustic quality of the church.

The aim of the present paper was to determine the current acoustic situation and to compare seven different electro-acoustic systems proposed by different firms, through the study of the main acoustic parameters. Moreover a speech intelligibility test, in compliance with ISO TR 4870, was carried out in the Cathedral in order to

obtain a subjective judgement. Finally a technical-economic analysis let to choose the best solution respecting the great historical value of the Cathedral. A post operam measurement session was carried out in the church, in order to obtain a comparison between the demo version of electro-diffusion system and the final situation.

Results are extremely good: the value of reverberation time and other common acoustic indexes such as Clarity, Definition, STI and RaSTI show meaningful improvements at all frequencies.

They are evident if compared to the past situation: as an example, Acoustic Pressure Levels values are uniform for all over the Cathedral, providing a very good uniformity of the level in all the church..

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