CADP2 Technical Notes Vol. 1, No 1

CADP2 Design Applications
The Average Complex Summation

Introduction

Before the arrival of commercial computer sound system design programs in 1983, level prediction for multiple sources was necessarily simplistic. The available room coverage design methods utilized:

- device on-axis sensitivity with path losses to balance source levels and
- device coverage angles, sometimes with overlays, to determine the angular positioning between sources.

This process was meant to achieve even room coverage and sometimes did. Consideration of exactly how the various arrivals merged at any given room listening position were left to intuition since the real computation was far beyond any reasonable, cost-effective method.

With the advent of a computer assisted design program, the direct field sound pressure level could be predicted across the entire listening area from multiple sources. In conjunction with measured spherical device files for pattern loss information, the program introduced two methods for merging multiple signal arrivals to a given room location: Power Summation and Phasor Summation [1]. These two summation strategies have since remained the mainstay of prediction programs without significant alteration; but both have practical limitations.

Signal Merge Strategies

Power Summation:

The Power Summation method assumes that all arriving signals are uncorrelated. As such, phase is ignored and the MS (mean square) value of each signal's pressure contribution is taken and summed. The SPL for two equal level arrivals would be 3 dB greater than that of a single arrival.

$$\mathrm{p}_{\mathrm{rms}}{}^{2} = \sum_{j=1}^{N} \mathrm{p}_{j}{}^{2} \qquad \text{(A)}$$

The Power Summation method is fast and simple. The strategy is especially practical if the sources are in far proximity, separated by more than approximately ten times the wavelength.

If the devices driven by a common signal are in near proximity and yet are not close enough (a fraction of a wavelength) to be considered reasonably coherent, the Power Summation method will totally overlook the resulting signal level anomalies produced throughout the coverage area. The finished results of a near proximity system, designed while ignoring the phase information, can be disastrous.

Phasor Summation:

The Phasor Summation method uses the path distance from each source to a far field summation point to determine the level and phase of each arrival for a complex (vector) addition of the signals. All sources are assumed to be driven by a common signal. The predicted SPL for two equal level, coherent arrivals will be 6 dB greater than that of a single arrival.

$$p_{rms}^2 = \left(\sum_{j=1}^{N} p_j \cos\varphi_j\right)^2 + \left(\sum_{j=1}^{N} p_j \sin\varphi_j\right)^2 \qquad \text{(B)}$$

The Phasor Summation method depicts the signal merges with adequate accuracy (within given data restrictions) and computes sound field anomalies that really do occur. But an important assumption, often overlooked, is that the phase effects are calculated only at one chosen frequency and are not averaged across a frequency band, e.g. a one or one-third octave band [2]. The Phasor Summation, if incorporated at all, has been implemented as a single frequency calculation in every prediction program released since.

The calculated prediction results of a Phasor Summation over a coverage area will often appear much worse than listening experience suggests. When device separations are in far proximity the resulting prediction values appear so random as to be useless, especially if the results are to be presented to a client.

Average Complex Summation:

Since the Power Summation ignores real anomalies and the Phasor Summation exaggerates the severity of the anomalies by presenting only a single frequency in a band of information, neither signal merge strategy appears to properly demonstrate the real listening environment. Some new strategy that characterizes the whole frequency band is required.

The Average Complex Summation, ACS, is a method that employs the complete band of information. While some type of averaging was always thought desirable and practical it was not recognized that it can be a perfectly valid characterization. The studies of the ear's critical bandwidth have intimated that broad band program material should not be represented by a single tone [3,4]. More recently, listening tests have demonstrated that loudness and timbre of reproduced sound can best be characterized by one-third octave band measurements [5,6] and the prevalence of one-third octave band real time analyzers is an indicator of this preference.

The ACS strategy uses typically a one or one-third octave band and computes in that band the true RMS sound pressure level. If a complete transfer function for the device is provided, an accurate complex summation prediction can be computed [7]. Even when the phase information for the device is not included, some of the phase error naturally present in any single frequency complex summation process will be averaged out in the ACS process.

$$p_{rms}^{2} = \frac{1}{n}\sum_{i=1}^{n}\left[\left(\sum_{j=1}^{N} p_{ij}\cos\varphi_{ij}\right)^{2} + \left(\sum_{j=1}^{N} p_{ij}\sin\varphi_{ij}\right)^{2}\right] \qquad \text{(C)}$$

Signal Merge Comparison Study

A comparison of the predictions for the three signal merge strategies and actual measurements are shown in Figures 1-8. The measured area is a 20' by 40' rectangle with source pairs in two configurations; the first in near-proximity (4' separate) and the second in far-proximity (20' separate.) A monophonic 1 kHz octave band noise signal and a real time analyzer are used for the procedure. The sources are at +10' elevation, adjusted to zero degrees pitch and azimuth. The SPL measurements were made on a 2' by 2' grid, providing 210 values for comparison.

In the near proximity study (Figures 1-4), the Power Sum prediction. (Figure 1) conceals the destructive coverage anomalies shown in the Phasor Sum (Figure 2.) The Average Complex Sum (Figure 3) retains the coverage anomalies that dominate throughout the frequency band. Although the measured resolution is course, there is excellent pattern correlation between the measured values (Figure 4) and the predicted ACS values (Figure 3).

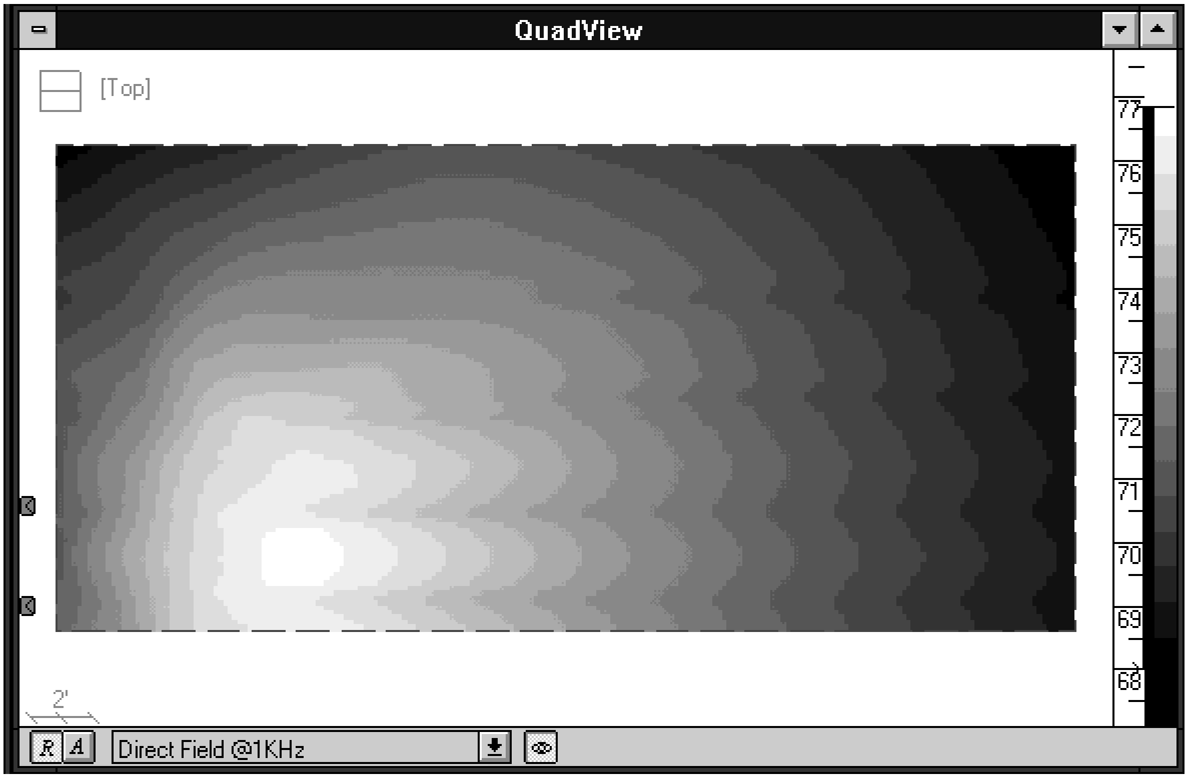

Figure 1. Power Sum prediction for 2 sources @ 4' separation

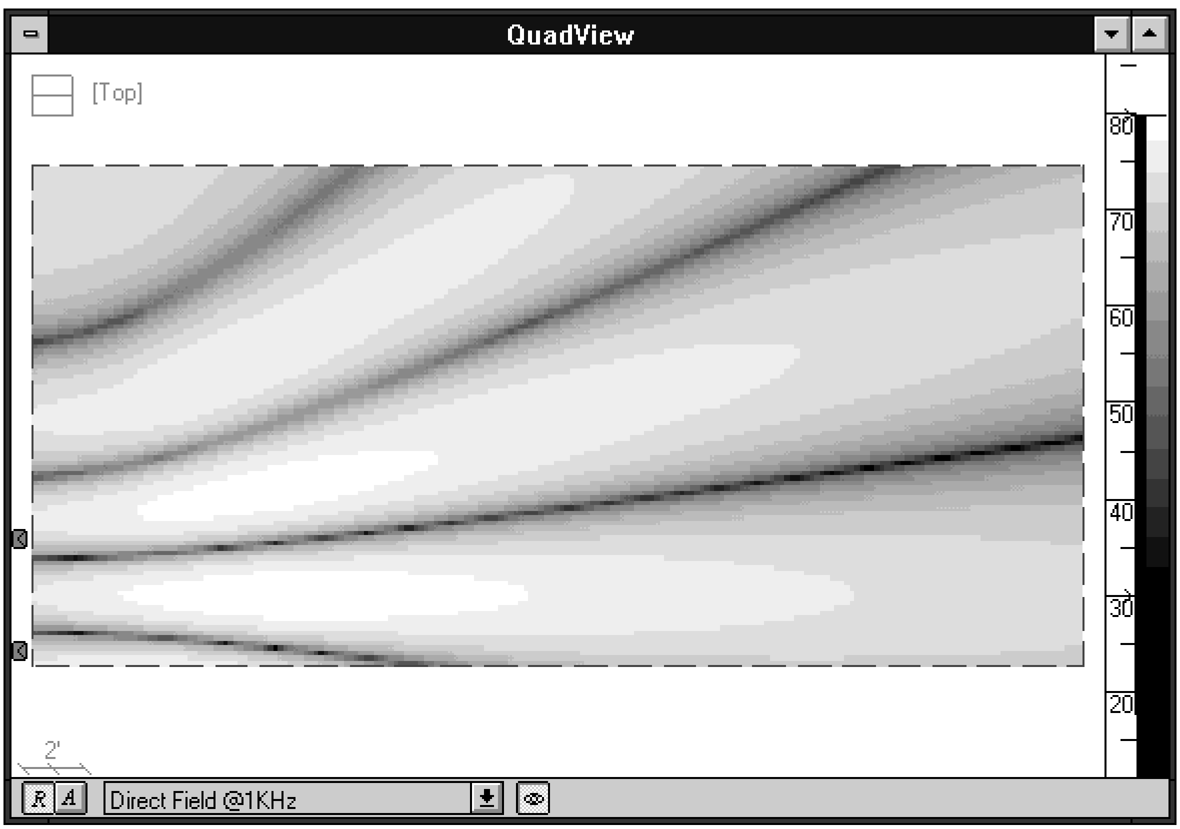

Figure 2. Single Complex Sum prediction for 2 sources @ 4' separation

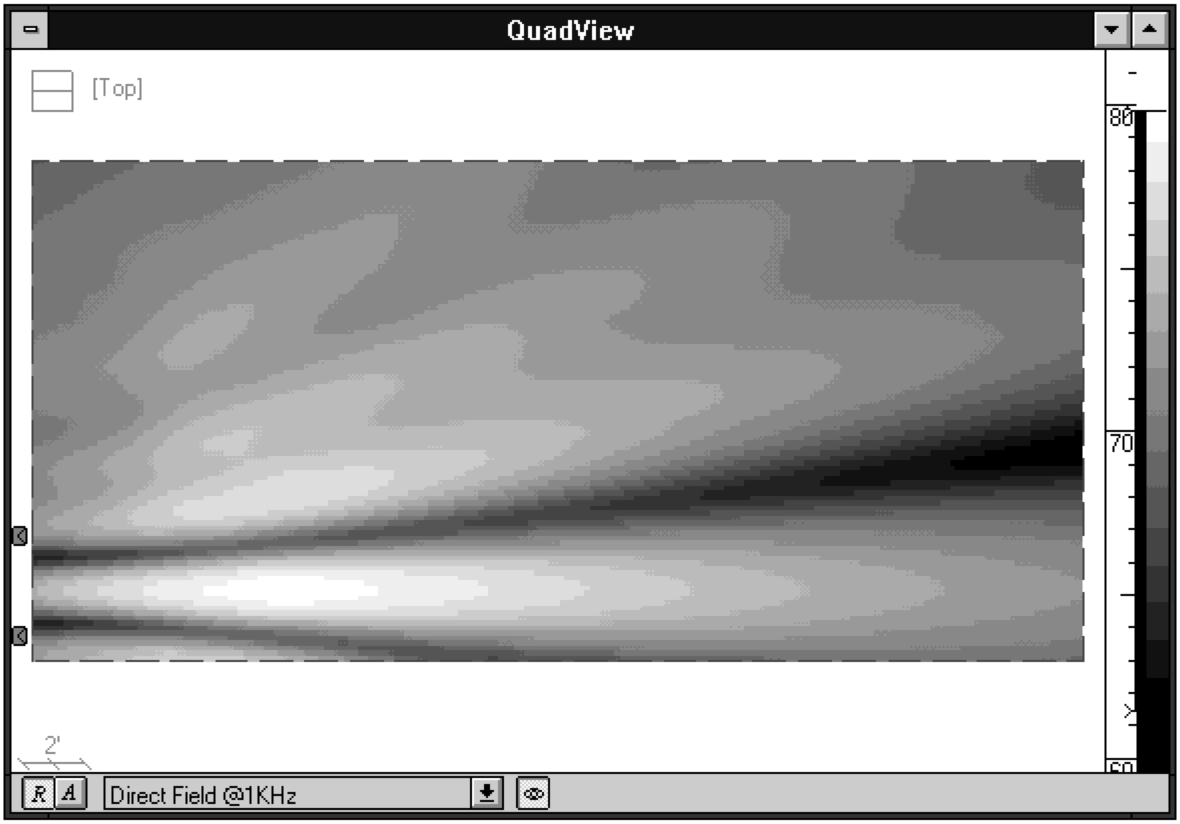

Figure 3. Average Complex Sum prediction for 2 sources @ 4' separation

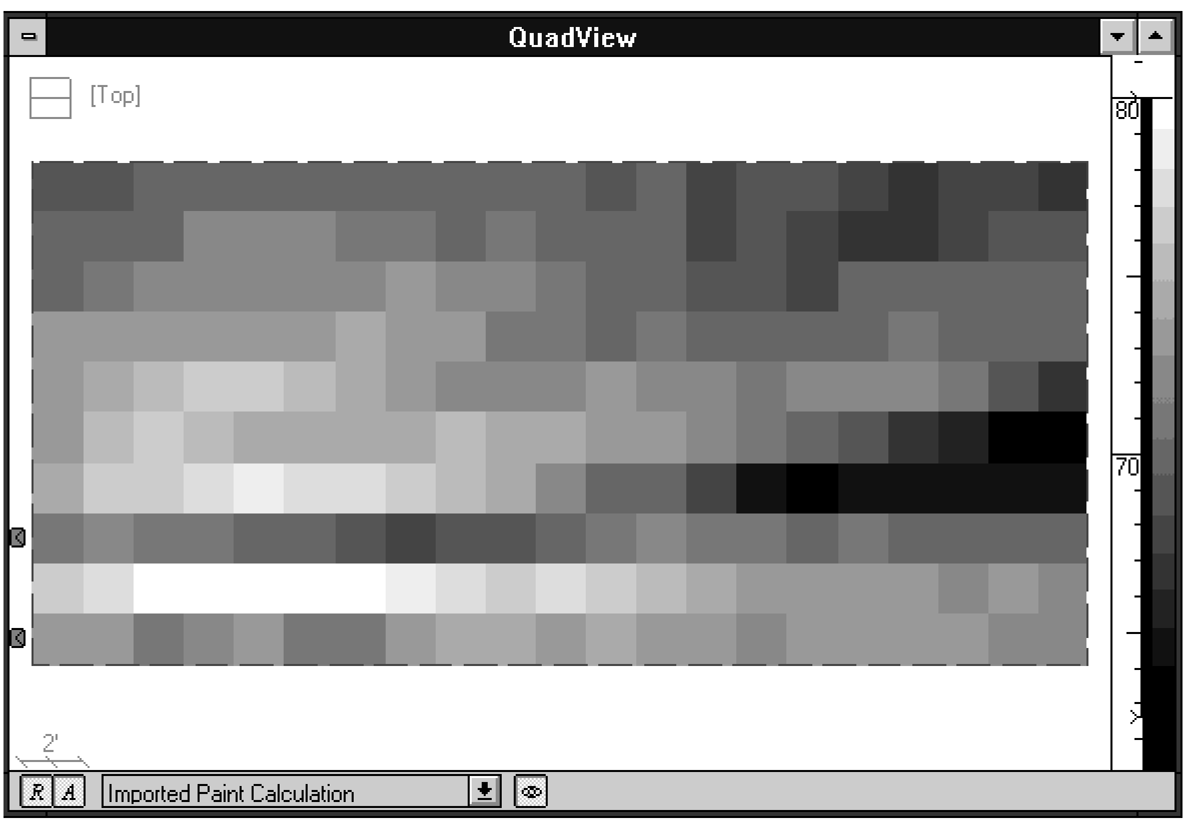

Figure 4. Measured SPL for 2 sources @ 4' separation (2' resolution, uncalibrated)

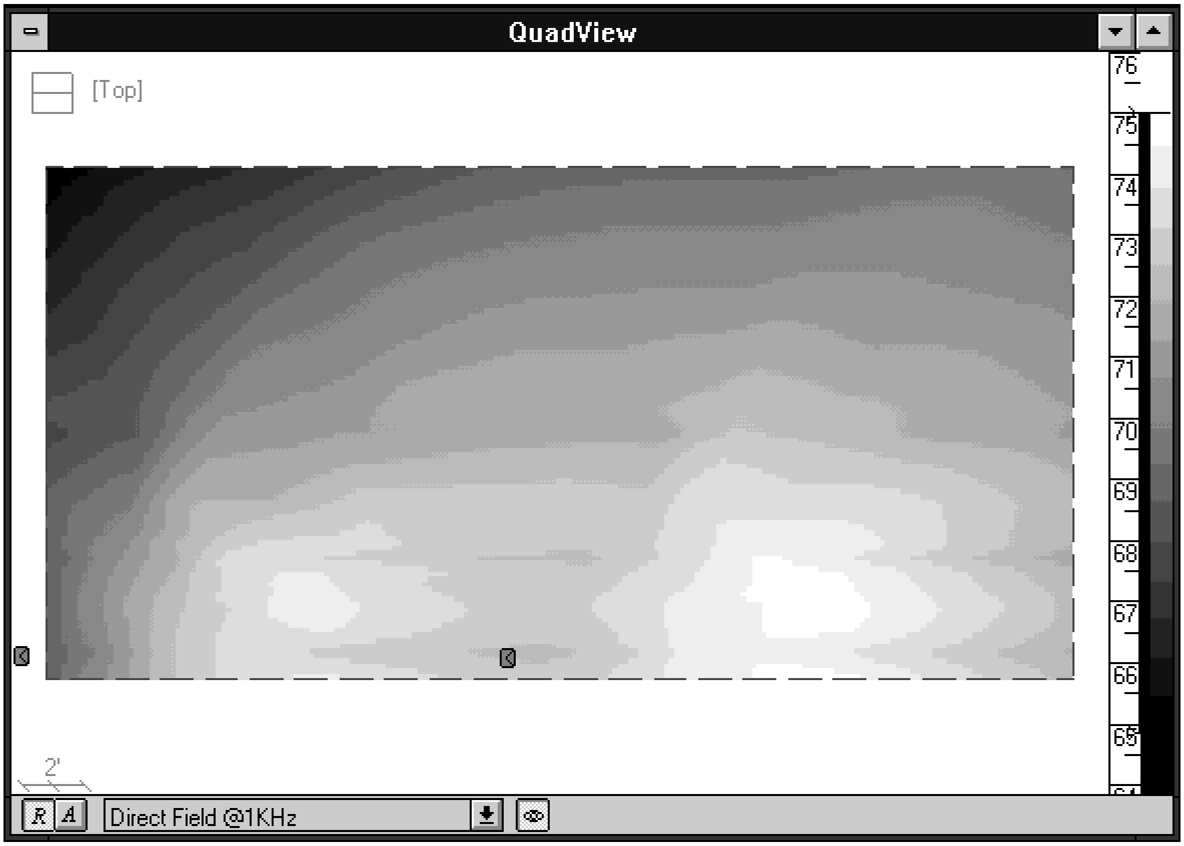

Figure 5. Power Sum prediction for 2 sources @ 20' separation

Figure 6. Single Complex Sum prediction for 2 sources @ 20' separation

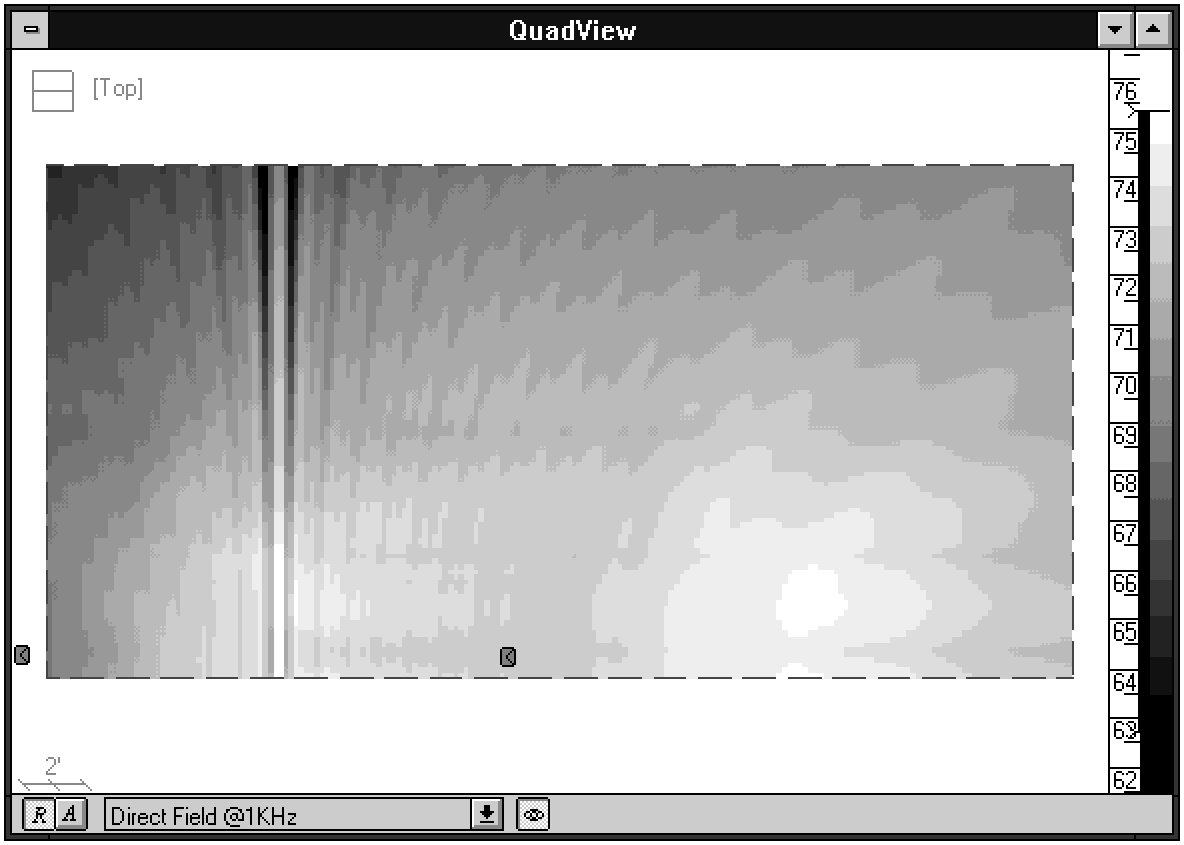

Figure 7. Average Complex Sum prediction for 2 sources @ 20' separation

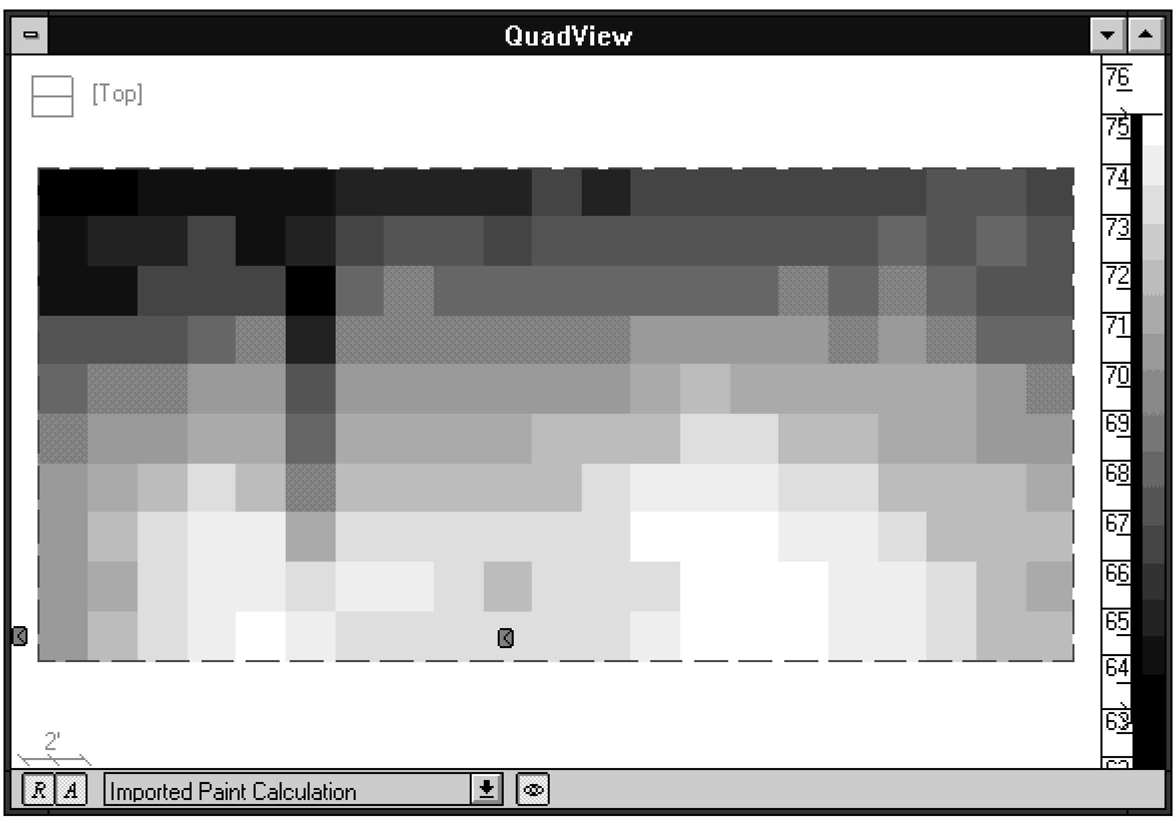

Figure 8. Measured SPL for 2 sources @ 20' separation (2' resolution, uncalibrated)

In Figures 9-12 a dinner theater with a small center cluster and distributed ceiling speakers demonstrates the failings of the Power and Phasor Summation strategies to properly represent the total system coverage. For comparison, the scale in all calculations has been adjusted so that the dB range is constant.

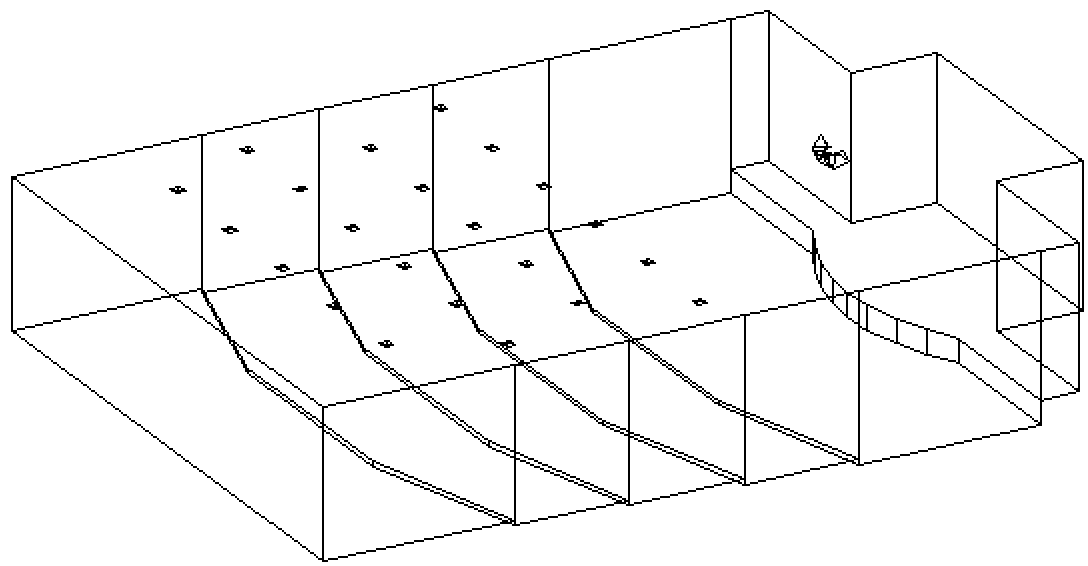

Figure 9: Small live theater with central cluster and delayed distributed speakers

The Power Sum calculation in Figure 10 predicts the contributions from the distributed ceiling speakers but does not display the phase interaction from a slight misalignment of the three horn cluster.

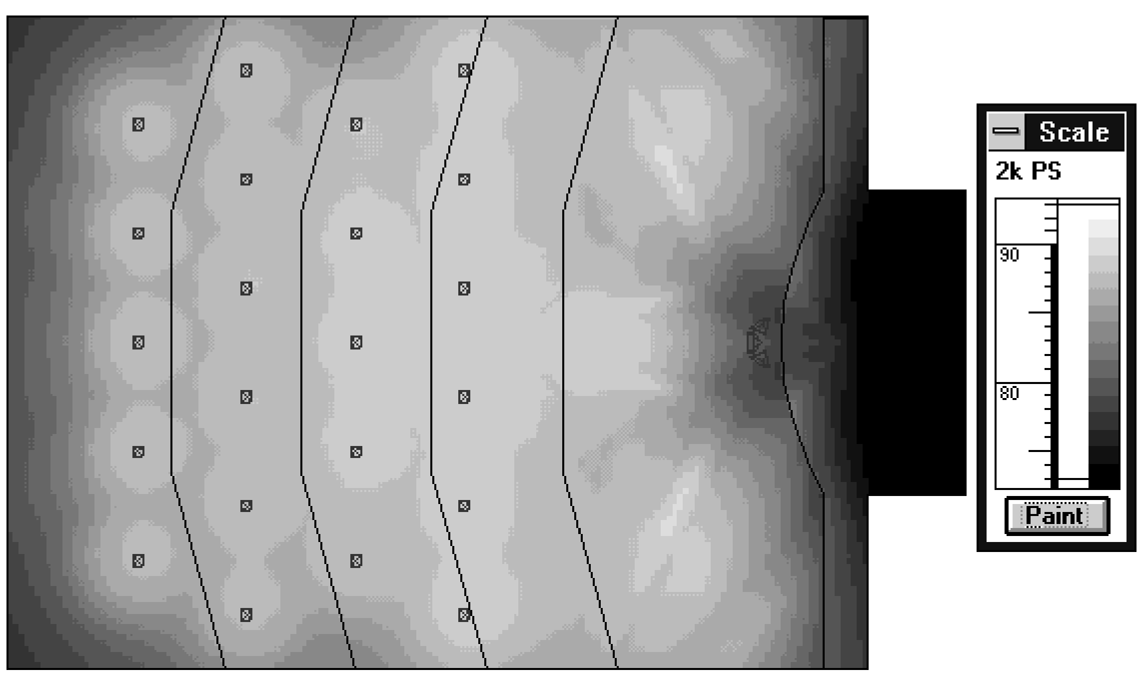

Figure 10: Predicted Room Coverage - 2 kHz Power Summation dB-SPL

The single frequency Complex Sum calculation in Figure 11 predicts the multiple lobes of the three horn cluster but misrepresents the contributions from the distributed speakers.

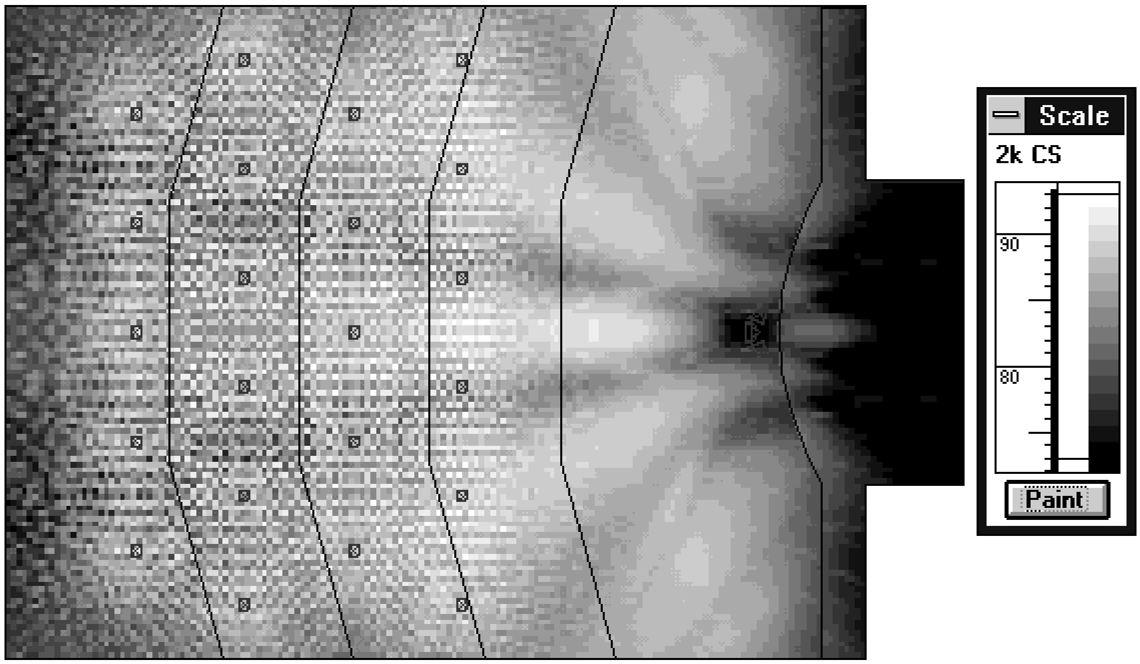

Figure 11: Predicted Room Coverage - 2 kHz Complex Summation dB-SPL

The Average Complex Sum calculation in Figure 12 predicts the multiple lobes of the three horn cluster and correctly displays the contributions from the distributed speakers.

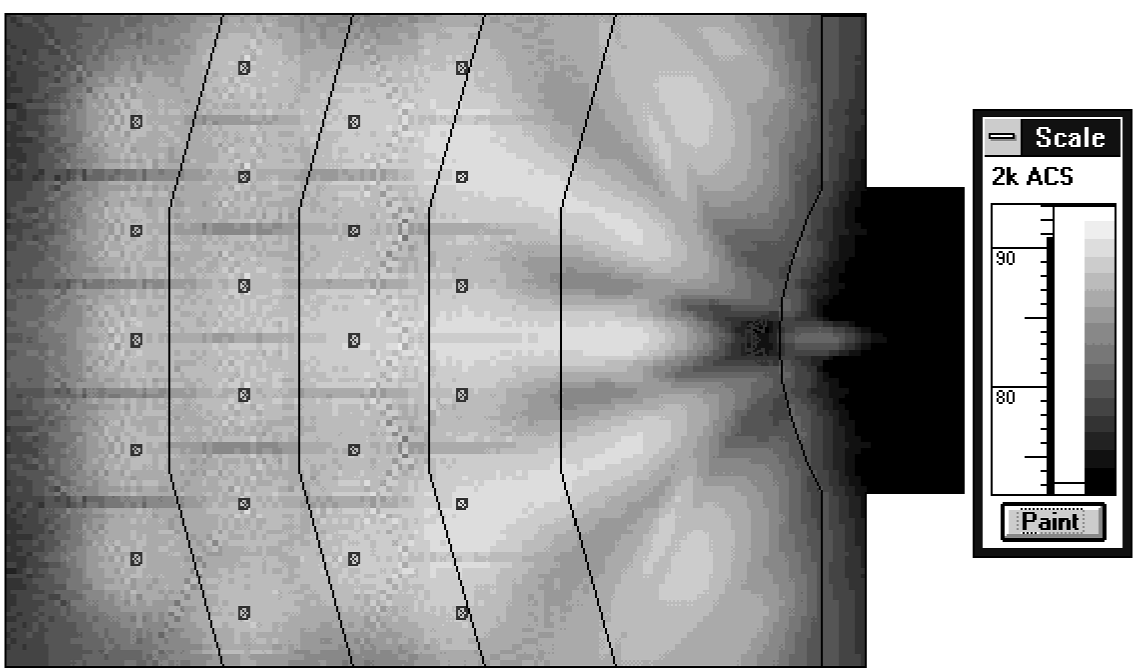

Figure 12: Predicted Room Coverage - 2 KHz Average Complex Summation dB-SPL

Acknowledgments

John M. Eargle for resource information and review.
Carol L. Long for assistance in field measurements.

References

1. D. Albretz, J. Eargle, D.B. Keele, Jr. and R. Means A Microcomputer Program for Central Loudspeaker Array Design *74th AES Convention NY,* October 1983

2. CADP User Manual v 2.0 pg38-39 JBL Incorporated © 1984

3. Juan G. Roederer, Introduction to the Physics and Psychophysics of Music Springer-Verlag, N.Y. 1975, 2nd edition

4. John M. Eargle, Handbook of Sound System Design ELAR 1989

5. H. Staffeldt & E. Rasmussen, The Subjectively-Perceived Frequency Response in Small and Medium-Sized Rooms. *SMPTE Journal*, July 1982.

6. H. Staffeldt, Measurement and Prediction of The Timbre of Sound Reproduction. *J. Audio Eng. Soc*. June 1984.

7. H. Staffeldt, Measurement and Application of High Resolution Complex Polar Patterns for Sound Reinforcement Loudspeakers *91st AES Convention NY,* October 1991