Direct and Reflected:

Understanding the Truth with Y-S^3

-Speaker System Design Guide-

December 2008

Introduction

Y-S^3 is a speaker system design software application. It is especially useful in determining speaker placement. The user can easily enter the desired venue shape and calculate the three-dimensional coverage area for given speaker placements and angles.

Furthermore, Y-S^3 can provide valuable information about many of the points that must be considered when designing a speaker system by (1) calculating sound pressure distribution while taking into account speaker interference, (2) calculating the responses at specific points, and (3) calculating floor SPLs (sound pressure levels) caused by changing the system gain.

This guide explains how the Y-S^3 computations can be used in the actual system design process by using examples of speaker target configurations, response evaluations for specific points, and output level configurations. Y-S^3 is based around the concept of inputting simple room geometry information to determine the appropriate speaker configuration, so it only computes the effects of direct sound. However, actual sound fields are affected by reflected sound waves from walls, floors, and ceilings. Therefore, it is advantageous to understand at the system-design stage how the results of direct sound computation will correspond to the response of the actual sound field. This guide includes actual measurements to show how computed results correspond to actual sound field responses.

The examples in this guide use a 600-seat multi-purpose hall with a trapezoidal floor plane. The width of the hall is 22 m, the depth is 24 m (from the front of the stage to the wall behind the seats), the height of the ceiling is 14 m (the maximum ceiling height above the seats), and the reverberation time is 1.2 seconds (for a 500-Hz octave band sound with empty seats and the curtains down).

Conditions of the Venue

- ✧ Hall: 600-seat, multi-purpose hall
- ✧ Speaker type: One speaker array composed of two IF2112/64 speakers
- ✧ Speaker location: In the front at a height of 8 m (7.2 m above the stage floor)

1. Setting the speaker arrangement

Y-S^3 can produce contour diagrams for each speaker array or for each speaker within a speaker array. This allows the user to adjust the speaker arrangement while checking the floor-level coverage area. If the areas covered by individual speakers overlap significantly, sections of phase interference appear over a wide area and cause reinforcements (peaks) and cancellations (dips)*. Y-S^3 can produce color maps of the sound pressure distribution that can be used to evaluate phase interference. However, because Y-S^3 only computes the effects of direct sound, the computed results will be different than the actual sound pressure distribution in a hall, which is affected by direct and reflected sound. When designing a speaker system, it is important to understand how the effects of reflected sound will be manifested.

In the example below, a two-speaker array is placed in the center position. This example compares the computed areas of phase interference for the given speaker configuration to the actual measured sound pressure distribution in a real hall.

* Please note that all speakers produce phase interference when arrayed to some extent.

☑ Speaker target configuration

- How splay angle affects the speaker targets

  The first example shows an evaluation of each speaker target based on the splay angle. In Y-S^3, the user can click to switch to Single Mode display and view contour diagrams of the target areas of each speaker in the array. The user can also change the bandwidth and the central frequency of the contour diagram by changing the Frequency and Band items in the upper left of the window. The example below shows the average of the results for each octave (1/1 OCT Band).

  For example, if Splay Angle is set to 60.0, the black squares that represent the speaker targets appear very close to the walls, giving the impression that the splay angle is too wide for the seating arrangement. If the Splay Angle is then set to 50.0, the speaker targets appear near the middle of the left and right areas, just about where they should be.

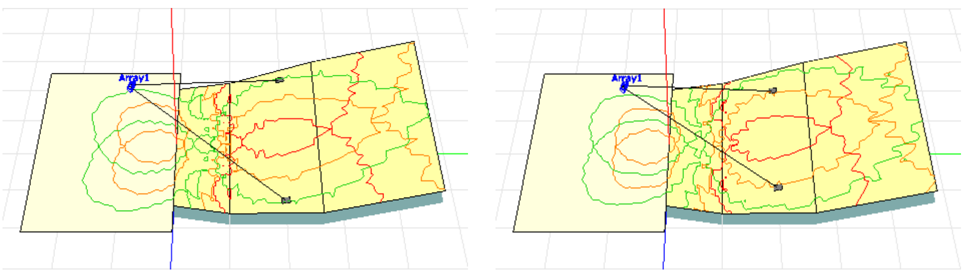
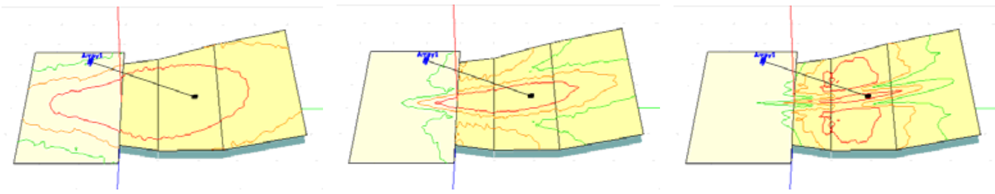


Figure 1: Splay angle adjustment (left: 60.0, right: 50.0)

- Viewing the coverage area

The next step is to check whether the coverage area of the speakers is appropriate.

In Y-S³, the user can click to switch into Array Mode and view a contour diagram for the entire array. The figure below shows the results for a splay angle of 50.0. Looking at this contour diagram, it is clear that the current array configuration covers the important central area of the seats, but in the 1 kHz contours (an area of midrange critical for good speech intelligibility), areas of phase interference between speakers are also evident.



Checking the coverage area

(left: 250 Hz, center: 1 kHz, right: 4 kHz, all 1/1 OCT Band)

☑ Checking sound pressure distribution

- Sound pressure distribution differences between frequency bands

The next step is to check the effects of phase interference between speakers. In Y-S³, the user can click to switch into SPL mode and view a color map of the sound pressure distribution.

In the 250 Hz band, areas of phase interference do not appear. This is because the wavelengths contained within the band are long compared with the distance between the speakers.

In the 1 kHz band, areas of phase interference do appear between the speakers. Whether or not these areas of phase interference are tolerable depends on the purpose of the system being designed, but because the volume differences in the central area of the room are within approximately 10 dB, one could conclude that the level of phase interference is tolerable.

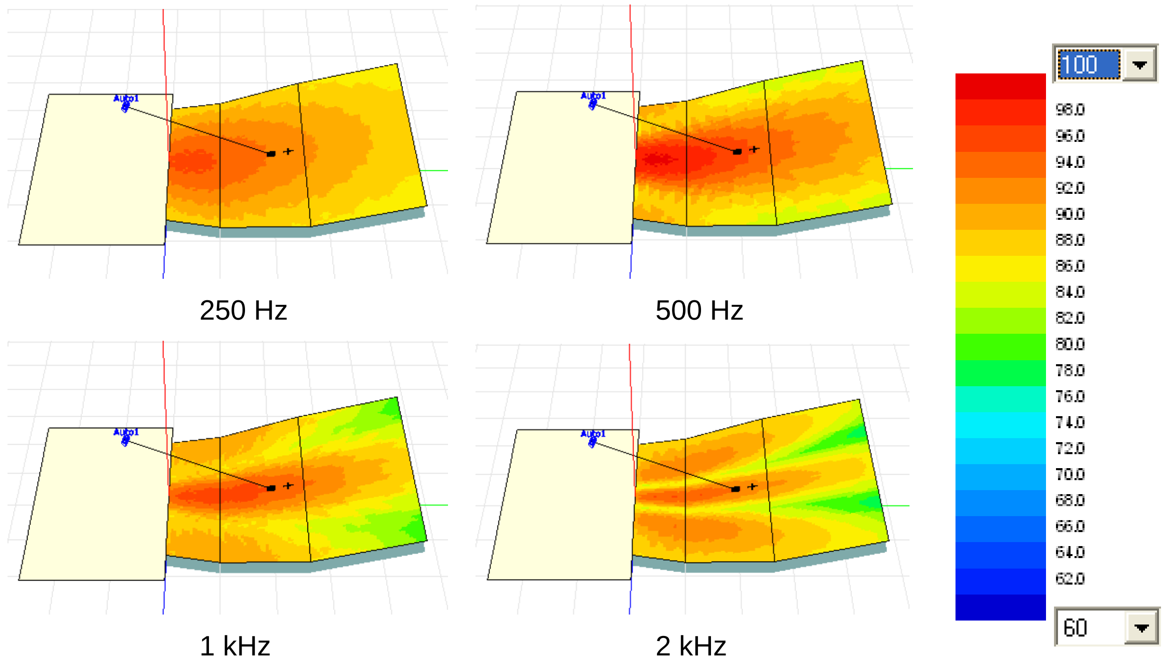


Figure 2: Sound pressure distributions for different frequency bands
(all 1/1 OCT Band; the listed frequency is the center frequency)

☑ Comparison with Actual Measurements

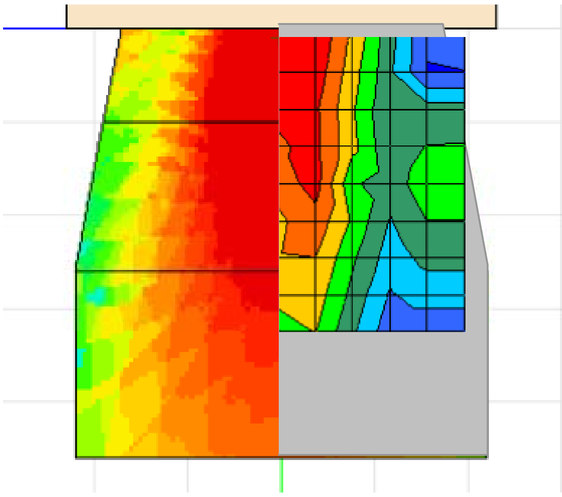
In the actual sound field, the areas of phase interference between speakers will be affected by reflected sounds. To help explain how the effects of reflected sounds are manifested, a comparison between the computed results and actual measured results is given below.

- Measurement Conditions

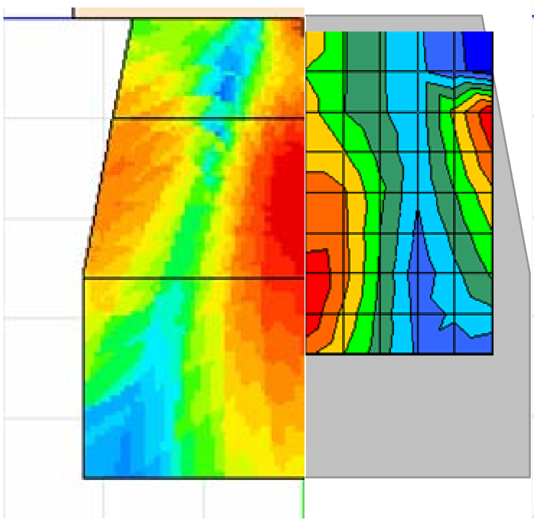
  In the actual measurement, two IF2115/64 speakers were installed with a splay angle of 50 degrees. They were hung on a pole and installed 7.2 m above the stage floor. Omnidirectional condenser microphones were installed in thirty different locations to measure impulse response.

- Areas of Phase Interference in the Middle to High Frequency Bands

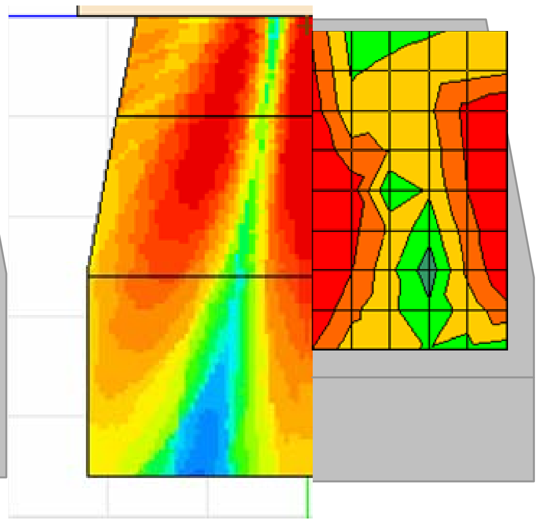
  Figure 3 shows the sound pressure distributions for the 500 Hz, 1 kHz and 2 kHz bands. The right sides of the figures show the actual measured results, and the left sides of the figures show the computed results. Both show the 1/1 OCT Band results. The measured results show the values integrated over 1 second after the reception of direct sound. As discussed earlier, the YS3 computed results indicate areas of phase interference between the two speakers in the 1 kHz and 2 kHz frequency bands. A similar pressure distribution appears in the measured results. Pressure distribution differences between computed and measured results vary depending on how sound is reflected from the walls, but if the target area has been configured appropriately, similar phase interferences between speakers will appear in both the computed and measured results in the middle frequency bands. Therefore, it can be concluded that using the computed results of direct sound only to reduce areas of phase interference will have beneficial effects on the actual sound field.



500 Hz



1 kHz

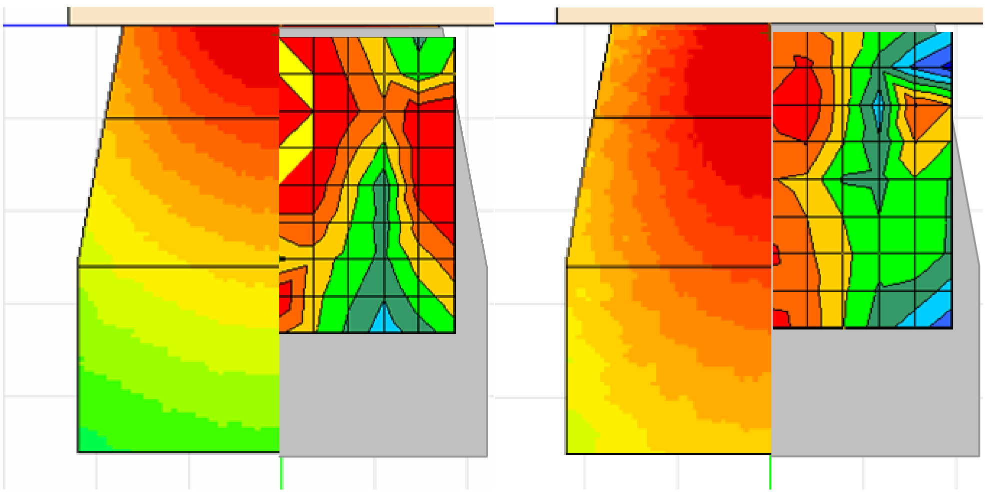


2 kHz

Figure 3: Sound pressure distributions by frequency band (middle frequency bands) (left diagram: the results of Y-S^3, right diagram: measured results)

- Effects of Reflected Sound in the Low Frequency Bands

  Figure 4 shows the sound pressure distributions for the 250 Hz and 125 Hz octave bands. In the computed results on the left side of each figure, no dips caused by phase interference are indicated between speakers because the wavelengths of the frequencies in question are relatively long compared to the distance between the speakers. However, areas of phase interference do appear in the measured results on the right side of each figure. These areas are most likely formed through interference between direct sound from the speakers and initial reflections from the walls. The wide and even areas of phase interference between direct and initial reflected sounds indicated in the low frequency bands are caused by two factors. One factor is the large amount of sound reflected from the walls caused by the wide directivity of the speakers. The other factor is that because the variations in the wall surface are small compared with the wavelengths in the low frequency band, there is no diffusion effect. The influence of reflected sound may manifest itself as unevenness in sound pressure distribution levels. This can also be interpreted as the influence of the venue type. For typical enclosed speakers, directivity is difficult to control in the low frequency bands, so you cannot change the phase interference in the low frequency bands by changing the speaker angles. It is important to understand that this type of interference will not appear in speaker arrangement evaluations that only take direct sound into account, but that it will appear in the actual sound field.



125 Hz 250 Hz

Figure 4: Sound pressure distributions by frequency band (low frequency bands) (left diagram: the results of Y-S^3, right diagram: measured results)

2. Evaluating the Response at Specific Points

The effects of interference between multiple speakers are manifested in the response at a specific point through dips in frequency characteristics. In the actual sound field, it is expected that the depth of the dips will be reduced by reflected sound.
As in the previous section, this section compares the results of direct sound computations to those of actual measurement results in the case when a two-speaker array is placed in the center position of a hall.

☑ Frequency Characteristics at a Specific Listening Point

- Evaluating Sharp Dips

  Figure 5 shows the computed and measured results at point A (x = 6 m, y = 6 m). Point A is 6 m to the left of the center of the seating area (approximately in the middle of the left side of the seating area). The blue line represents the Y-S^3 computed results. The red line represents the measured results in the actual hall. It shows the values integrated over 15 ms after the reception of direct sound. The pink line also represents the measured results in the actual hall, but it shows the values integrated over 100 ms after the reception of direct sound. The spectrum of the measured results was acquired through an 8192-point Fourier transform and then converted into 25-point moving averages. The vertical axis of the graph represents relative sound pressure levels, and the maximum value for each line is set to 0 dB.

  In the Y-S^3 computed results (the blue line), a dip of approximately 20 dB occurs at approximately 1.2 kHz. It is difficult to determine the significance of this dip, but Y-S^3 has an auralization feature that simulates the audio response so that you can evaluate it.

  One must be aware that in actual sound fields, these kinds of dips are mitigated by the effects of reflected sound. In the values integrated over 15 ms (the red line), the dip appears in a relatively high frequency range, but it is mitigated to within 10 dB even at its deepest point. This dip also appears in the values integrated over 15 ms and in the values integrated over 100 ms, indicating that the frequency response of the strong direct sound that arrives from the speakers has a strong influence on the overall frequency response of the initial reflected sound, and thus also has a strong influence on the listening experience. This further underscores the importance of checking the effects of interference between speakers at the design stage.

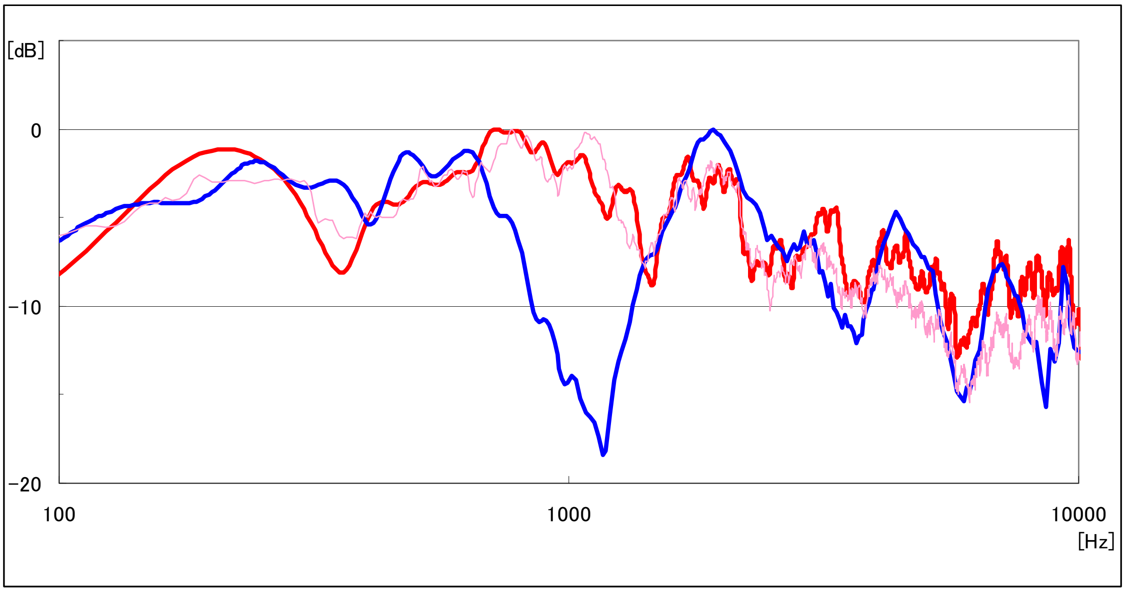


Figure 5: Measured and computed results at X = 6, Y = 6

Blue: Y-S^3. Red: Measured results integrated over 15 ms. Pink: Measured results integrated over 100 ms. (The measured results are moving averages.)

- Evaluation of High-Frequency Drop-Off

  Figure 6 shows the computed and measured results at point B (x = 1 m, y = 10 m). Point B is approximately in the center of the seating area. The blue line represents the Y-S^3 computed results. The red line represents the measured results in the actual hall. It shows the values integrated over 15 ms after the reception of direct sound. The spectrum of the measured results was acquired through an 8192-point Fourier transform and then converted into 25-point moving averages. The vertical axis of the graph represents relative sound pressure levels, and the maximum value for each line is set to 0 dB.

  In the Y-S^3 computed results (blue line), there are no dips in any particular frequency bands, but the frequency characteristics decline steadily starting at approximately 4 kHz. The reason that the frequencies that are subject to phase interference are rather high is because the difference between the distances between the two speakers and point B is small.

  This high-frequency drop-off also appears in the measured results at the actual hall. In the values integrated over 15 ms (the red line), the characteristics begin declining at approximately 2 kHz. They decline by as much as 20 dB. The dips observed at point A that were caused by reflected sound from the floor do not appear in the same frequencies at point B. The reason for this is probably that the ways in which sounds are reflected are different at the two points because the measurement for point A was made in the seats while the measurement for point B was made in the walkway.

The above example shows that the frequency responses at specific points computed using Y-S^3 are similar to those that appear in actual sound fields. Understanding this during the design phase will facilitate better measurements and adjustments after the speakers have been arranged.

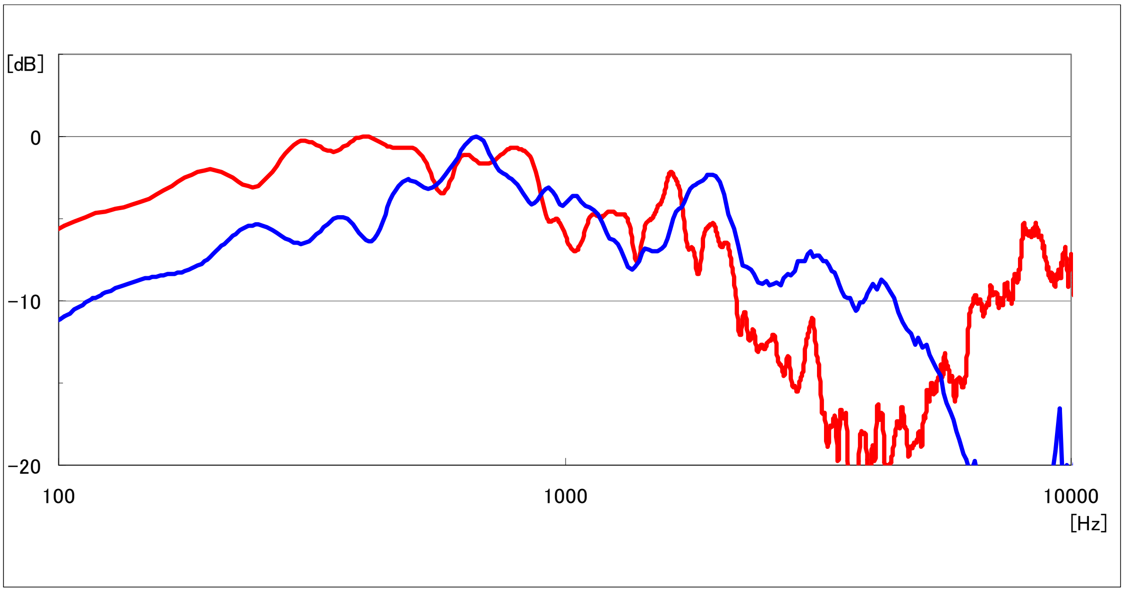


Figure 6: Measured and computed results at X = 1, Y = 10

3. Configuring Output Levels

You can use Y-S^3 to estimate the sound pressure levels at different points for different amp types, gains, and input levels. The computed levels can be used to determine whether the system you are designing can obtain the sound pressure levels that you want. In computations based on direct sound, the SPL attenuates linearly as the distance from the speakers increases, but in an actual sound field, sound diffusion results in mitigation of the rate of SPL attenuation as distances increase.
This section provides an example of how to configure levels using Y-S^3, and it compares the level attenuations at different distances in computed values based on direct sound to those in the measured values in an actual hall.

☑ Configuring Sound Pressure Levels with Y-S^3

- On the Config tab in the Speaker Property dialog box, you can configure the input level and the amp attenuator, and consider what configuration will yield the SPL that you want.
- When you first set up the speakers or when you change the speaker type, the recommended amp is selected and the level settings are at their default values (+4.0 dBu for the input level and -10 dB for the attenuator level A).
  For these settings, the overall SPL at a point where X = 0 and Y = 11.5 would be 90.7 dB.

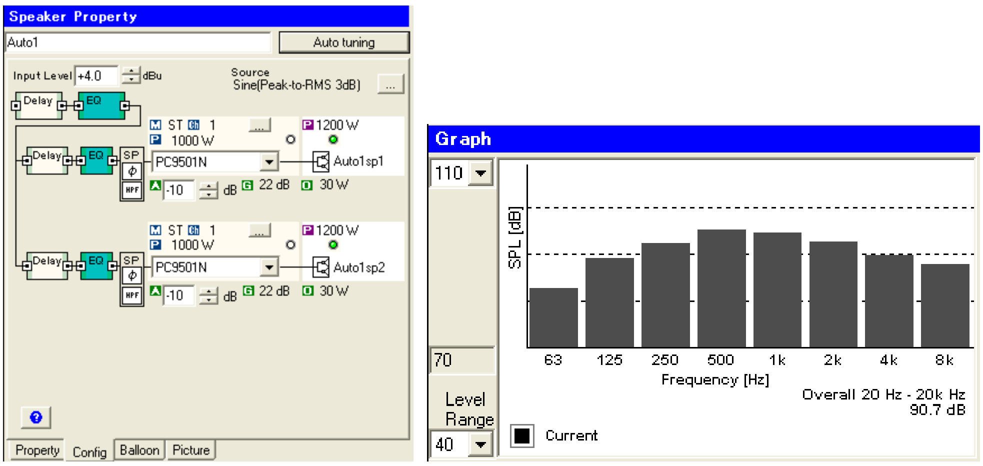


Figure 7: Default level settings

- You can use Y-S^3 to change the input and/or attenuator levels and compute the maximum SPL for the rated power or compute the approximate SPL for a certain nominal input level.

For example, to change the SPL to approximately 100 dB, you could set the amp attenuator level to -6dB and set the input level to 10 dBu. Doing so would change the overall SPL to 100.7 dB.

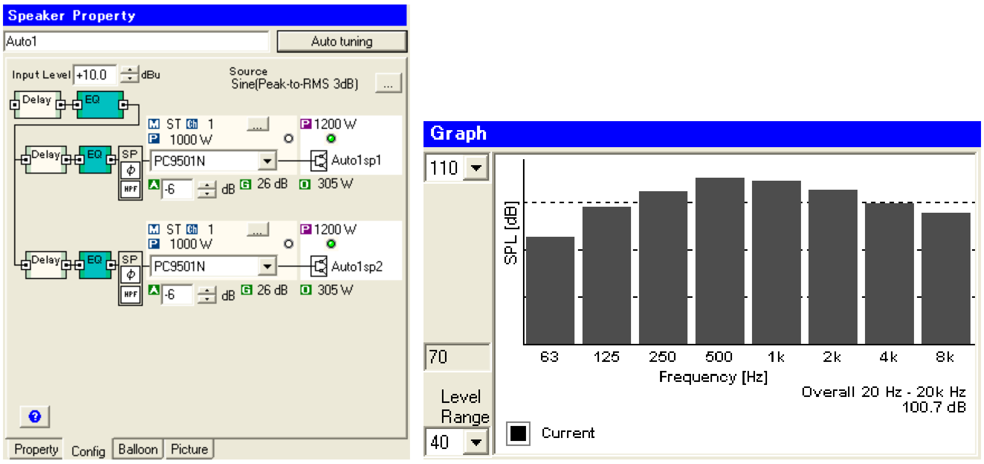


Figure 8: Adjusted level settings

➢ Given the settings shown above, the SPL at a distant point, X = 0, Y = 22.0 for example, would be 95.4 dB. However, in an actual sound field, the level will not decrease that much due to the effects of reflected sound. This must be taken into account when evaluating results and configuring a system. The following section reveals the effects of reflected sound by comparing the computed results to the actual measured results in a hall.

☑ Comparison of Level Attenuations with Respect to Distance

We installed a speaker on the stage and compared level reductions for different distances. We measured sound levels for every 2 m up to a distance of 18 m from the speaker. We also computed sound levels for the same conditions using Y-S^3. Figure 9 shows the results for the different distances. The horizontal (X) axis represents the distance from the sound source, and the vertical axis represents the sound pressure level relative to the level at 3 m from the sound source. The Y-S^3 computed results for 1 kHz attenuate steadily, but the measured results show that there is almost no attenuation after 13 m because of sound diffusion. There is a central walkway at the point 11 m away from the speaker, and the unique sound reflection conditions there are evident in the plot of the measured data. The Y-S^3 computed results for 2 kHz attenuate more gradually than those for 1 kHz. The reason for this is that the seats are on a rising slope, so as the seats become further from the stage, they also face the speaker more directly, and the sound pressure levels rise as a result of the speaker directivity. The measured results for 2 kHz stop attenuating after 13 m, just like the results for 1 kHz. Also, the effects of speaker directivity on the levels are hidden by the effects of the reflected sound.

When configuring a speaker system based on computations of direct sound, it is important to remember that at the actual venue, steady-state SPL will rise at more distant points as a result of sound diffusion. If you fail to take this point into account when trying to achieve specific SPLs at more distant points, you may be misled by the computed results into selecting a system whose overall SPLs are much larger than necessary. The point at which level attenuation caused by distance is mitigated varies depending on the size and sound absorption conditions of the venue. Formulas for determining theoretical values such as those shown in figure 10 have been proposed by researchers.

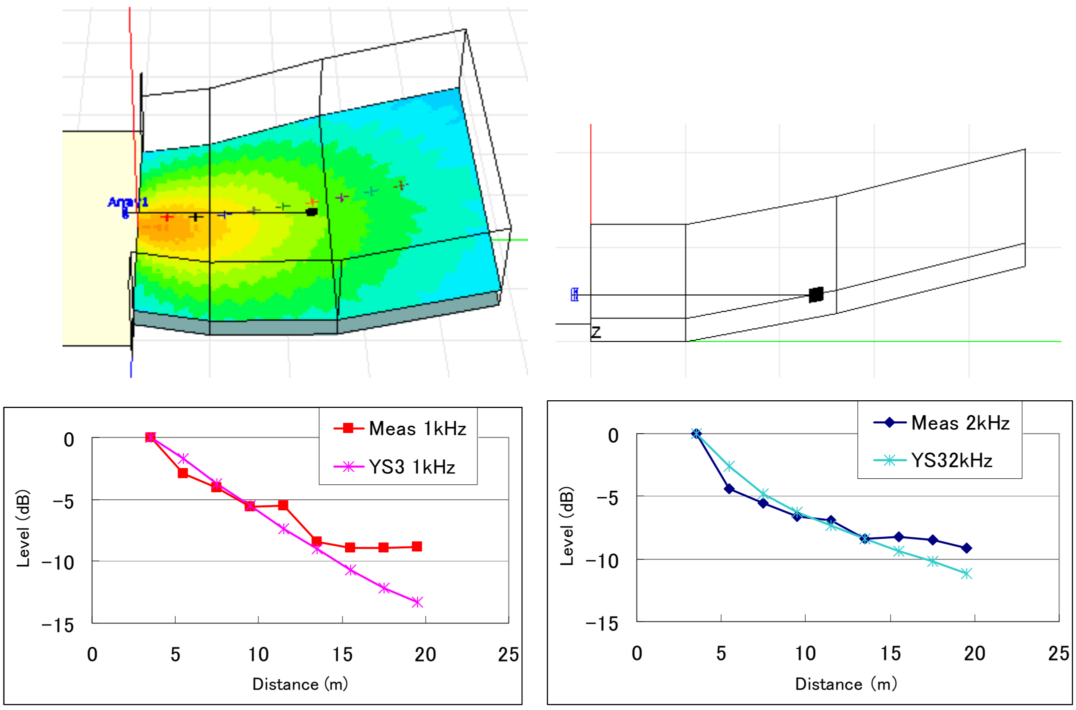


Figure 9: Comparisons of level attenuations caused by distance

Top: relationship between the sound source and the points of measurement.

Bottom: measured and computed results.

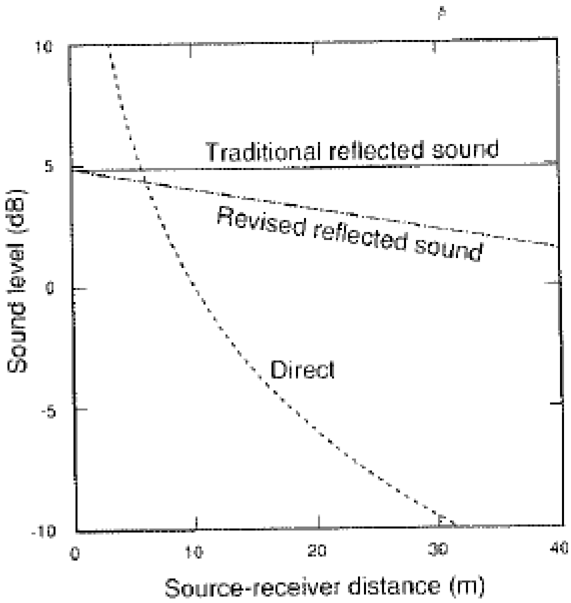


Figure 10: Theoretical attenuation levels of direct and reflected sounds based on revised formula by Barron

(M. Barron, *Auditorium Acoustics and Architectural Design*, [E&FN Spon, 1993], 32)