TOA

TOA Electronics ***Speaker Guide***

TOA

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Welcome to the TOA Speaker Guide

TOA has long been recognized as a manufacturer of high-quality, flexible, and reliable amplifiers. For over 75 years, we have also been an innovator in the design of high-performance speaker systems for a wide range of applications. TOA has been at the forefront in the development of specialized loudspeaker technologies for public spaces. TOA produced some of the first professional speaker systems that utilized dedicated electronic processing to optimize the speaker's performance. TOA engineers presented the first AES papers on adaptive filter equalization and the use of all-pass filters for flat-phase speaker tuning. Our test facilities include one of the world's largest anechoic chambers and state-of-the-art facilities for acoustics and reverberation simulation. TOA was among the first to adopt the RASTI speaker intelligibility rating method and we rigorously test our speakers using TEF 20 analyzers. TOA also assisted with the Japanese translation of the classic text by Don and Carolyn Davis, *Sound System Engineering,* and has long been a sponsor of Syn-Aud-Con sound system design seminars.

The purpose of this design guide is to provide sound contractors and systems integrators with a convenient, easy-to-use reference to design small- and medium-sized TOA distributed speaker systems. The guide discusses the main parameters and trade-offs involved in designing distributed speaker systems and provides rules-of-thumb to help specify and implement them.

Disclaimer: *This design guide does not cover all of the general concepts underlying sound system design and installation, which would require several hundred pages. This guide is not meant to replace the participation of an experienced consultant or engineer.*

References: For more detailed information about sound system design principles, we recommend the following two excellent books:

Sound System Engineering, Second Edition, Don and Carolyn Davis, 1975, 1987 by Howard Sams & Co. ISBN: 0-672-21857-7

Handbook for Sound Engineers: Third Edition, Glen Ballou, Editor, 2001, Butterworth and Heinemann. ISBN: 0-240-80454-6

Acknowledgements

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Chapter 1: Getting Started: System Design Steps

System design is essentially a process of answering the right questions in the right order. Answering the following questions will provide the basis of a sound design for your system. Not included in the list is the question of project budget, which is always a guiding factor.

1. **Where will the system be used?**

   Is it indoors or outdoors?

   If indoors, is it highly reverberant?

   How large is the space?

   What mounting/installation options are available?

Answers to the following questions will guide the project and influence subsequent questions.

2. **What will the system be used for?**

   Is it for music, speech, signaling tones, or a combination?

   What level of fidelity, or sound quality, is required?

   Is strong bass response important?

   What level of speech intelligibility is required?

Defining the requirements of the system is critical to the success of the installation. Different sound system applications and their requirements are discussed in Chapter 2: *System Applications*.

3. **How loud must the system be?**

   How much noise is present in the listening environment?

   Will the system be used for high-level foreground music?

Use an SPL meter to measure ambient noise levels on site during typical operating conditions. An inexpensive SPL meter is available from Extech (http://www.extech.com). See Chapter 5: *Using Speaker Specifications* for an overview of how to calculate the required sound pressure and power levels, based on the background noise you measured or estimated.

4. **What type of speakers are right for the job?**

   Will the job require ceiling, wall-mount, or other types of speakers?

   Will subwoofers be needed to enhance the bass response?

Since the best speakers for one job may be amongst the worst for another job, proper matching of the speaker to the installation is important. See Chapter 3: *Speaker Types* for a discussion of the types of speakers most commonly used in distributed speaker systems, and the application each is suited for.

5. How should the speakers be distributed throughout the space?

What layout pattern will be used (i.e., square or hexagonal)?

How far should speakers be spaced from each other?

It is often said that "location is everything." Where speakers are concerned, this is often the case. See Chapter 2: *System Applications* and Chapter 6: *Layout and Spacing for Distributed Speaker Systems* for rules-of-thumb to establish the appropriate number and placement of speakers.

6. How much power and what kind of wiring is required?

An amplifier with inadequate power can render a sound system unintelligible at normal operating levels. Matching the amp(s) to the speaker(s)—and selecting the proper connecting cable—are important ingredients of speaker system design. See Chapter 7: *Amplifier Selection* and Appendix A: *Wire Size Charts* for this critical information.

7. Is equalization required?

In many cases, an equalizer can help balance the sound of a system. When microphones are used, equalization may also improve gain before feedback. See page 20 for a brief discussion of how equalizers function in distributed sound systems.

Chapter 2: System Applications

Paging

Paging systems communicate voice announcements throughout a building or area. Distributing intelligible speech is the main requirement of a paging system. Consider the following points when designing a system for paging:

- Speech *energy* is concentrated in the range 350 Hz – 5 kHz. System frequency response should be smooth and consistent in this range.
- Speech *intelligibility* is most affected by system performance in the range 1–5 kHz. Consistent coverage of the listening area is especially important in this frequency range.
- People's voices can vary significantly in loudness, sometimes leading to high peak (short-term) demands on system power. Excessive distortion (due to overdriven amplifiers or speakers) can reduce intelligibility by masking the critical consonant sounds. See *Sensitivity Ratings and the Decibel* on page 18, *Determining Maximum Output: Sensitivity and Power Handling* on page 21, and Chapter 7: *Amplifier Selection* to match your speakers and amplifiers to the application.

Additional intelligibility factors are discussed in Chapter 4: *Audio Basics*.

Speech Reinforcement

Sound systems that must amplify speech for extended periods of time (i.e., a meeting room or a lecture hall) pose special challenges to the system designer. Consider the following points when designing a speech reinforcement speaker system:

- It is important to avoid *dead spots* (quiet or dull-sounding areas within the listening area) to maximize intelligibility and avoid feedback. Feedback occurs when the gain is increased in an attempt to supply more volume to the dead areas.
- Using multiple mics to reinforce multiple speakers, as in a panel discussion, presents a special challenge: Doubling the number of microphones reduces the system gain (relative volume) that can be reached before feedback by 3 dB.
- If more than four microphones are used, consider employing an automatic mixer, such as the TOA AX-1000A, to help maximize system gain.
- The *gain*, or relative volume, that can be achieved depends on the relative positions of the microphones, the loudspeakers, and the listeners, in combination with the acoustical characteristics of the mics, loudspeakers, and room. *Sound System Engineering* is an excellent reference for maximizing system gain (see page 9 for reference).

Background Music

Background music places different demands on a sound system than paging. Consider the following points when designing a background music system:

- Natural-sounding music reproduction requires a minimum frequency response range of 100 Hz – 10 kHz that is wider than the basic speech range.
- Background music sources typically have limited dynamic range, and have a lower peak volume requirement than foreground music or paging.
- Background music does not usually require the precise spectral balance and consistency of coverage as speech; this allows wider speaker spacing in background music-only systems.

Foreground Music

Foreground music plays a more prominent role in the space's primary function (i.e., music in a bar or fitness center) than background music and is generally louder and more dynamic. The special demands of foreground music include the following:

- At higher levels, the quality of the sound system is more noticeable. The frequency response range should be wider and distortion levels lower than a typical background music system.
- Depending on the application and client taste, the bass response should extend down to 60 Hz or lower, high frequency response to 16 kHz or higher.
- One or more subwoofers may be needed to provide additional bass output.
- The amplifier power and the sensitivity and power handling ratings of the speakers must be adequate to reproduce the music's peaks without distortion. This could mean using five or even ten times more power than is used in a typical background music system. See *Power, Volume, and Decibels* on page 17 for an overview of the relevant factors.

Voice/Music Combinations

Most installed sound systems are required to reproduce both speech and music. Therefore, they must have both the smooth response and even coverage of a speech system and the wide frequency range and continuous output capability of a music system. In a distributed speaker design, this means using good quality speakers and relatively close spacing.

Presentation Audio

Sound for video and audio-visual presentations should be treated as a combination speech and foreground music application. To reproduce sound effects (i.e., movie sound or attention-getting AV presentations), amplifier power and speaker power handling should be adequate to handle the highest program peaks.

Chapter 3: Speaker Types

There are four speaker types for distributed systems: ceiling, wall-mount, in-wall, and paging horns. Subwoofers are also used in some systems to augment the bass. The following sections discuss the characteristics and best uses for each type.

Ceiling Speakers

Figure 3-1 F-101C/M, F-121C/M ceiling speakers

Ceiling speakers distribute sound unobtrusively from a relatively low ceiling over a large floor area. When installed with the proper spacing and sufficient amplifier power, a good quality ceiling speaker provides uniform coverage and satisfactory frequency response for live speech reinforcement and background music applications.

Wall-mount Speakers

Figure 3-2 BS-1030B/W wall-mount speaker

Wall-mount speakers, which are generally full-range, multi-way systems, are often well suited for foreground music. They are also applicable if the ceiling is very high or is otherwise not suitable for mounting speakers. Speakers may be mounted directly to the wall's surface (i.e., TOA's H series), or with a swivel bracket (F- and BS- series).

In-wall Speakers

Figure 3-3 H-1 in-wall speaker

Installing the speaker inside a wall is unobtrusive and deters theft. However, installation can be costly and proper aiming and positioning are often problematic. The TOA H-1 in-wall speaker overcomes this obstacle by using rotating speaker elements to aim sound where it is needed. Proper spacing is important, especially for speech intelligibility.

Paging Horns

Figure 3-4 SC Series paging horns

Paging horns can achieve a higher SPL than ceiling or wall speakers, but have limited frequency response, lower sound quality, and higher distortion levels. They are seldom used for music applications but are commonly used outdoors where long sound projection distances are needed. They are also used in noisy environments where high sound levels are required for intelligible messages (i.e., large public spaces, warehouses, and factories). When properly aimed and installed, their controlled coverage and reduced low frequency output increases the direct sound level and reduces low-frequency masking, which are significant advantages in large rooms. The TOA SC Series wide-range paging horns offer a compromise between high output levels and sound quality that is preferred for outdoor music applications.

Subwoofers

Figure 3-5 FB-100 subwoofer (left) and HB-1 in-wall subwoofer

Distributed music systems are often faced with the challenges of delivering clear, high-fidelity sound with enough power to overcome high ambient noise levels at an affordable price. Meeting these requirements has typically involved giving up good bass response because small speakers cannot reproduce low frequencies at high levels. Since many contemporary musical styles require powerful bass reproduction, adding a subwoofer is a cost-effective way to meet this new demand.

Chapter 4: Audio Basics

The Decibel

The *Bel*, named in honor of Alexander Graham Bell, was originally defined as the loss of signal level over one mile of telephone cable. A *decibel* is 1/10th of a Bel. Neither the Bel nor decibel have an explicit level, but are specified as a logarithmic ratio.

Sound Pressure Level

Sound Pressure Level (SPL) is the acoustic pressure reference for the dB. The minimum threshold of undamaged human hearing is considered to be 0 dB SPL. The threshold of pain for undamaged human hearing is 120 dB SPL.

Power, Volume, and Decibels

Since the decibel is an expression of relative level change, it can be used to describe volume levels in both the acoustical and electrical domains. *80 dB SPL* refers to an acoustic volume (loudness) level relative to the standard 0 dB reference. Changes in electrical power and voltage can also be described in terms of the dB (see *Sound System Engineering* by Don and Carolyn Davis for an in-depth discussion on the use of the decibel in sound system design). The following rules of thumb will help properly utilize the decibel in speaker system design:

- A change of 2 dB SPL in overall volume is the smallest change perceptible to the average listener.
- Increasing the volume by 3 dB requires doubling the amplifier power.
- Multiplying amplifier power by a factor of 10 increases SPL by 10 dB.
- Increasing the level by 10 dB SPL is perceived by a typical listener as doubling the volume.
- Voltage is not the same as power. Doubling voltage increases volume by 6 dB and multiplying voltage by 10 increases volume by 20 dB.

For the mathematically minded: *The following equation converts power differences to volume changes:* **level change in dB = 10 * log (P1/P2)***, where P1 and P2 are the power figures being compared in Watts.*

Sensitivity Ratings and the Decibel

A speaker's *sensitivity* is the on-axis loudness (dB SPL) measured at a specific distance that results from applying a specific amount of power (i.e., 1 W @ 1 m). The output level of the speaker at different power levels and distances can be calculated from this figure. For example: If a speaker's sensitivity is rated at 96 dB SPL with a 1 W input measured at 1 m from the speaker, then doubling the power to 2 W raises the output 3 dB to 99 dB SPL at 1 m. Doubling the power again to 4 W produces 102 dB SPL. For a discussion and examples of how to use sensitivity ratings, see Chapter 5: *Using Speaker Specifications*.

Attenuation over Distance: Inverse Square Law

The *inverse square law* describes how sound attenuates over distance. It states that volume (SPL) decreases 6 dB each time the distance from the sound source is doubled. This is due to the diffusion of sound radiating from the sound source over a spherical area. As the radius of a sphere is *doubled*, its surface area *quadruples*, effectively dividing the acoustical power by four. This is consistent with the discussion above of power, volume, and the decibel: dividing the power by 2 results in a 3 dB decrease in volume; dividing by 4 results in a 6 dB decrease.

For the mathematically minded: *The following equation converts a change in distance to a change in level for a spherically radiating source:* **level change in dB = 20 * log (D1/D2)***, where D1 is the original distance and D2 is the new distance.*

Speech Intelligibility, Acoustics, and Psychoacoustics

Speech intelligibility refers to the degree a listener can understand spoken words in a particular space. It is important to clearly hear and differentiate consonant sounds. The two basic parameters affecting intelligibility are the smoothness of the system frequency response curve in the speech range (about 350 Hz – 5 kHz) and the effective *signal-to-noise* ratio of the system (noise can include echoes, reverberation, distortion, and even out-of-band signals such as excessive bass). Good frequency response depends on selecting high-quality speaker components and locating and aiming them correctly. The following sections on masking effects and reverberation cover some often overlooked factors that affect achieving a good signal-to-noise ratio.

Masking, Upward Masking, and the Haas Effect

Masking refers to one sound being obscured by another so it is unnoticed or indistinguishable from the first sound. It is one of the main obstacles to speech intelligibility. Typical sound systems include a number of potential sources of masking effects.

Background noise is the most obvious: the sound system's normal operating level should be at least 15–25 dB above the background noise level.

High distortion levels in amplifiers, speakers, or other sound system components, is another possible source of masking. Excessive distortion is easily avoided by using high-quality equipment and following industry guidelines for proper gain structure. For a definitive discussion of sound system gain structure, see *Sound System Engineering*.

Late reflections, or late-arriving sounds from distant speakers, can be especially troublesome and can ruin both music quality and intelligibility. Good speaker layout avoids echoes from distant speakers. It is also important to properly place and aim speakers to avoid echoes from distant walls or other surfaces.

The *Haas Effect* refers to a characteristic of human hearing that perceives early reflections (i.e., from surfaces near the sound source or listener) as part of the original sound, while later reflections from more distant surfaces are perceived as discreet echoes. This characteristic can be used to advantage in room and sound system design, but can also indicate conditions to avoid. As a general rule, avoid strong reflections from surfaces more than 15 ft from either the sound source or the listener. Field experience indicates that reflections from surfaces 7–10 ft from the source or listener blend more smoothly with the direct sound. Very close reflections, within 4 ft of the source or listener, cause audibly wide notches in frequency response due to phase cancellation and should be avoided or moderated using acoustically absorbent materials.

Upward masking refers to the characteristic of a sound to mask not only other sounds in the same frequency range, but also sounds several octaves higher. This often overlooked aspect of human hearing can result in a loss of intelligibility when the lower frequencies predominate in a sound system—a common occurrence, especially with speakers with dispersion patterns that get narrower with increasing frequency. For example, an eight-inch ceiling speaker is omnidirectional below 400 Hz, but has less than 60° coverage above 2 kHz, resulting in excessive reflected and off-axis sound energy in the low frequencies.

Reverberation

Reverberation is another common source of masking-related intelligibility loss. Significant reverberation occurs in a large room (i.e., church, gymnasium, or auditorium) where repeated reflections merge into a seemingly continuous sound with a gradual rate of decay. Many installed sound systems are used in spaces where there is little or no significant reverberation. This design guide is applicable in these situations. When designing a speech reinforcement system for a large, reverberant room (RT60 > 2.5 s), we recommend consulting with a specialist in acoustical system design. More information on sound system designs for large rooms can be found in *Sound System Engineering*, and in *Handbook for Sound Engineers*.

Equalization

Equalization, or *EQ,* is the process by which the amplitude of discrete frequency ranges is adjusted. In distributed systems, EQ is most often used to compensate for speaker and room characteristics but can also be used for aesthetic enhancement. Whether and how much equalization to use depends on the performance standard and how the selected equipment performs in the acoustical space. Many applications do not require equalization. The benefits of using equalization include improved speech intelligibility, enhanced sound quality due to a better spectral balance, and increased gain without feedback. It is important to note that there is the potential for serious problems if the equalizer is set by an unqualified operator or mistakenly reset (i.e., someone cleans the unit and moves the faders). Security covers or dedicated preset equalizers can prevent these problems.

TOA offers a range of equalizer modules for our 900 series amplifiers that are optimized for specific H and F Series speakers. These cost-effective modules are preset and therefore tamper-proof. For larger sound systems, TOA also makes 1/3-octave and dual, 2/3-octave rack-mount equalizers, as well as a full-featured digital signal processing system that provides simultaneous equalization, delay, crossover, matrixing, and dynamics processing functions. For a more detailed discussion of the use of equalizers, see *Sound System Engineering* (see *page 9* for complete reference).

Chapter 5: Using Speaker Specifications

Determining Maximum Output: Sensitivity and Power Handling

A thorough system design must establish the maximum SPL required from each speaker at a given listening position. In general, a speaker should be able to produce a sustained long-term average level 15–25 dB higher than the background noise in its area. If the noise level is less than 45 dB SPL, the speaker should be able to produce a long-term average level of 70 dB SPL in the listening area, with undistorted peaks 10–20 dB higher. As noted on page 18, a speaker's rated *sensitivity* is the on-axis loudness (dB SPL) measured at a specific distance that results from applying a specific amount of power (i.e., 1 W @ 1 m). The sensitivity may be used to calculate loudness at other distances and power levels. Three specifications are required to calculate the maximum SPL capability of a speaker in its environment:

- The speaker/transformer's maximum continuous power rating, or the available amplifier power;
- The speaker's sensitivity rating (dB SPL @ 1 m on-axis with 1 W input);
- The distance between the listener and the speaker.

Using these three specifications, the maximum on-axis output can be calculated (the formulas for decibels gained with power and decibels lost with distance are presented in Chapter 4: *Audio Basics*). Since the formulas use the log function and require a scientific calculator, simplified charts (Figure 5-1 and Figure 5-2) are included here for convenience.

Example: A paging horn in an outdoor area needs to reach an average level of 90 dB SPL at 80 ft from the horn. A 30 W model is selected with a sensitivity of 112 dB, 1 W @ 1 m. To allow for short-term transients, 6 dB of headroom is added to the average level requirement, yielding a target level of 96 dB SPL.

Question: *How much power is needed to reach the target level?*

The rated sensitivity is 112 dB SPL, with 1 W @ 1 m. Use the chart for level change with distance (Figure 5-1) to see how much the level is reduced at 80 ft compared to the reference distance of 1 m (answer: 27.7 dB, or about 28 dB). This tells us that 1 W sensitivity at 80 ft is 112 – 28 = 84 dB SPL. This is 12 dB less than the target level of 96 dB. Use the chart for level change with power (Figure 5-2) to find the power required to increase the level 12 dB (answer: about 16 W).

Question: *What is the maximum long-term average output capability of the speaker at 80 ft?*

The rated long-term average power handling is 30 W. Use the chart for level change with power input (Figure 5-2) to find that our maximum output with 30 W at the reference distance of 1 m is approximately 127 dB SPL (112 + 15 dB). Use the chart for level change with distance (Figure 5-1) to see that at 80 ft, our maximum output will be approximately 99 dB SPL (127 – 28 dB). This gives 9 dB of headroom above the target level.

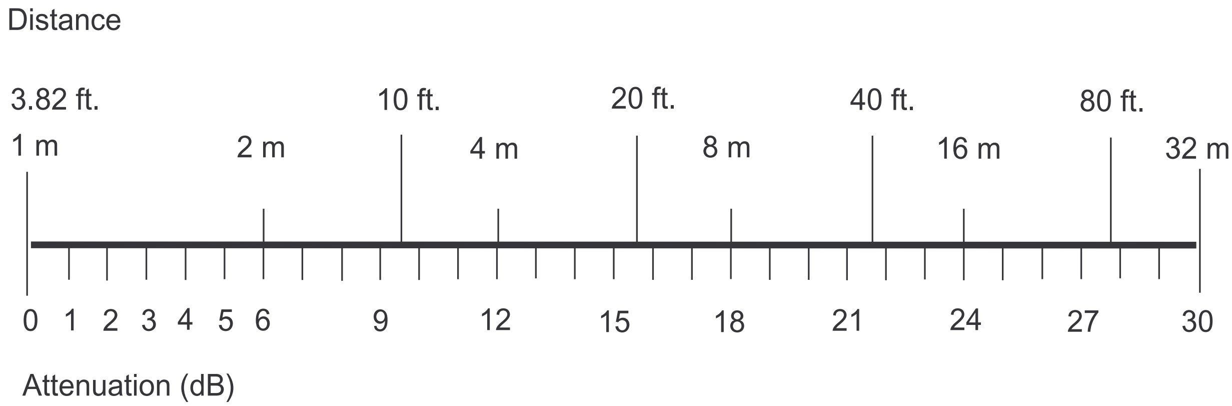


Figure 5-1 Level change with distance

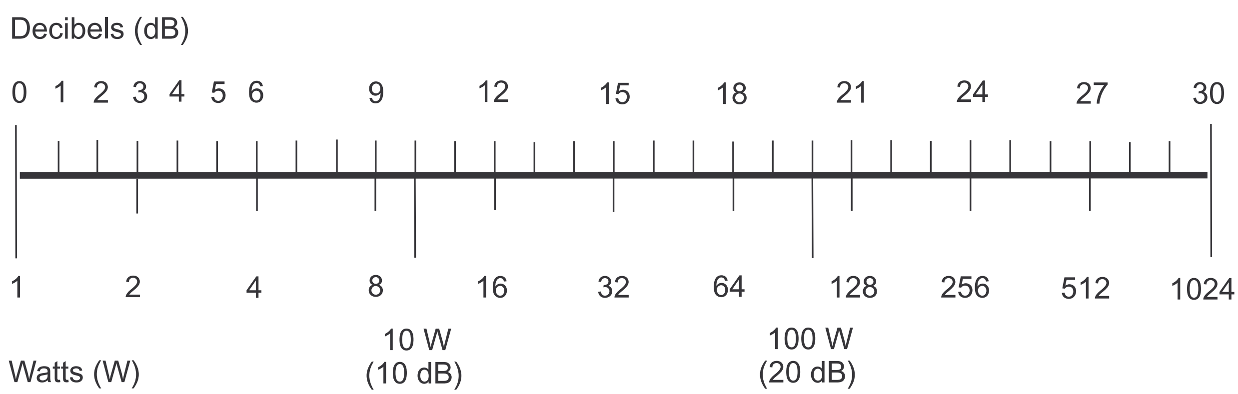


Figure 5-2 Level change with power

Coverage Angle

The *coverage angle* of a speaker is the angle within which the SPL is no more than 6 dB below the normalized on-axis level for a given bandwidth or frequency center. The desired coverage angle for a speaker depends on its role in the system, the number and spacing of speakers, and the acoustical environment. Typically, distributed speaker systems and background music systems need medium to wide dispersion speakers (coverage angle ≥ 60°). If the speakers are close to the listeners, for example in a low-ceiling room or pew-back speakers in a church, then wide dispersion is especially desirable (coverage angle ≥ 100°). Nominal coverage angle ratings of TOA speaker models are listed in Chapter 8: *Speaker Application Tables*. Polar plots depicting the coverage angle at standard frequency bands are found on our speaker specification sheets, which may be downloaded at www.toaelectronics.com.

Frequency Response

Frequency response refers to the frequency range over which the speaker responds, usually with a tolerance range for level variation. For example, a frequency response rating of 35 Hz – 18 kHz ±3 dB is typical of a professional studio monitor. The rating means that with constant input at all frequencies, the output over the stated frequency range will fall within a 6 dB window (3 dB above and below 0 dB) of variation. In general, a wider frequency response range indicates higher fidelity sound reproduction. However, restricting the frequency range (i.e., switching on the low-cut filter) can be an advantage in installed sound systems in order to:

- Avoid upward masking of consonants by low frequency energy, especially in reverberant spaces.
- Increase system headroom and avoid distortion at high levels.
- Maximize the overall system performance/cost ratio.

The following approximate frequency response guidelines are for specific applications and environments:

- Speech-only paging system (with or without emergency signaling) for a noisy environment: 350 Hz – 5 kHz
- Speech-only indoor environment: 120 Hz – 10 kHz
- Low-level background music: 100 Hz – 10 kHz
- Foreground music, high-quality background music and audio-visual applications: 80 Hz or lower – 16 kHz or higher. Achieving the desired low-frequency response may require a subwoofer in addition to high-quality main speakers.

Chapter 6: Layout and Spacing for Distributed Speaker Systems

Many installed speaker systems use a *distributed sound* design, which means that there are evenly spaced speakers spread throughout the venue, each covering a specific area. These speakers may be mounted in the ceiling, in or on the walls, or on columns or poles or other available structures. There are a number of possible approaches in laying out the speakers, or determining their placement in the room. Of course, the type of installation (ceiling, wall, etc.) must be known before deciding on a layout pattern.

Ceiling Speakers

Two key decisions guide the placement, or layout, of speakers in a ceiling speaker system:

- Speaker spacing;
- Layout pattern type (square or hexagonal).

The most important factors to consider when making these decisions are the speaker coverage area, the evenness of coverage desired, and the client's budget.

Speaker Coverage Area

In most cases, determining the area covered by a ceiling speaker involves projecting the speaker's (conical) coverage angle out to the distance between the speaker and the listener, and calculating the area of the resulting circle. Remember to account for the height of the listener in calculating the effective ceiling height. The wider the coverage angle, the larger the coverage area, the fewer speakers needed for the same evenness of coverage. Coverage areas for all of TOA's ceiling-mount speaker models are listed beginning on page 36 in Chapter 8: *Speaker Application Tables.*

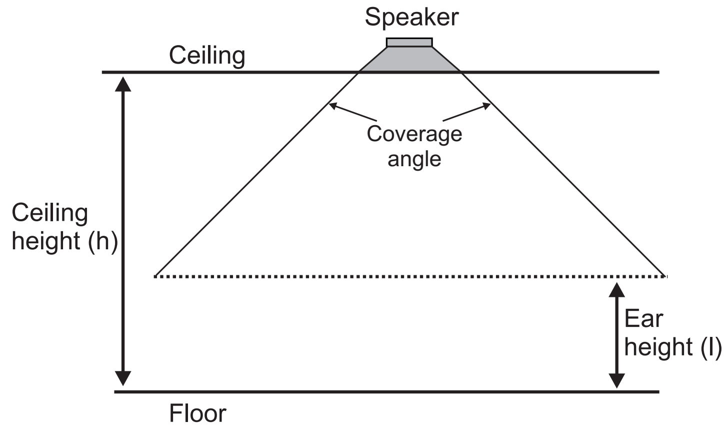


Figure 6-1 Ceiling speaker coverage area

The speaker's dispersion characteristics affect not only the required spacing and number of speakers, but also the overall sound quality and performance of the system. Large speaker cones (for example, an 8-inch full-range ceiling speaker) tend to produce narrow coverage angles in the high frequencies (called *beaming*), which cause dead spots between speakers unless they are spaced very closely together. Regardless of the speaker spacing, their overall diffuse-field output will still be lower in the high frequencies compared to their on-axis performance, leading to a dull sound in most of the listening area. TOA's F Series wide dispersion ceiling speakers include features engineered to avoid this common problem, resulting in higher sound quality throughout the listening area.

Coverage Area and Ceiling Height

As the ceiling height increases, the area a speaker can cover increases, but the power required to reach the same volume at the listener's position also increases. If the ceiling is very high (i.e., over 20 ft) some speakers may not be able to handle the power required for that distance. For ceiling heights greater than about 25 ft, consider alternatives such as mounting speakers on columns and walls, or suspending them below the ceiling, to get them closer to the listeners. Low ceilings are also challenging: for a ceiling lower than 12 ft, use a speaker with a coverage angle of 120° or greater.

Coverage Density vs. Budget

Once the coverage area per speaker is known, the next step is to decide how much overlap is needed between speakers. In distributed systems, higher density, or closer spacing of the speakers, provides more consistent coverage. If the speakers are spread too far, large portions of the listening area may suffer from inadequate volume and poor sound quality. The only downside of close spacing is cost. Balancing coverage density versus system cost is ultimately a subjective decision, but the information that follows can be a useful guide.

Layout Patterns

Square and hexagonal patterns are the layouts most commonly used in ceiling speaker systems. The choice of pattern depends on the best fit between speakers and room dimensions. The square pattern may also be rotated 45° or as needed to fit the shape of the room.

Speaker Spacing

Three standard speaker spacing methods are commonly employed in distributed systems. The spacing distance is based on the radius of the coverage area, and how much adjacent speakers should overlap. The amount of overlap determines the consistency of sound coverage: more overlap means more consistent loudness and sound quality. Standard spacing distances for all of TOA's ceiling speaker models are listed in Chapter 8: *Speaker Application Tables.*

No Overlap (spacing distance = 2r, where r is the radius of the speaker's coverage area): The coverage area of each speaker meets but does not overlap the coverage of adjacent speakers (Figure 6-2). This spacing will leave some gaps in coverage. It is used for low-cost background music and paging systems.

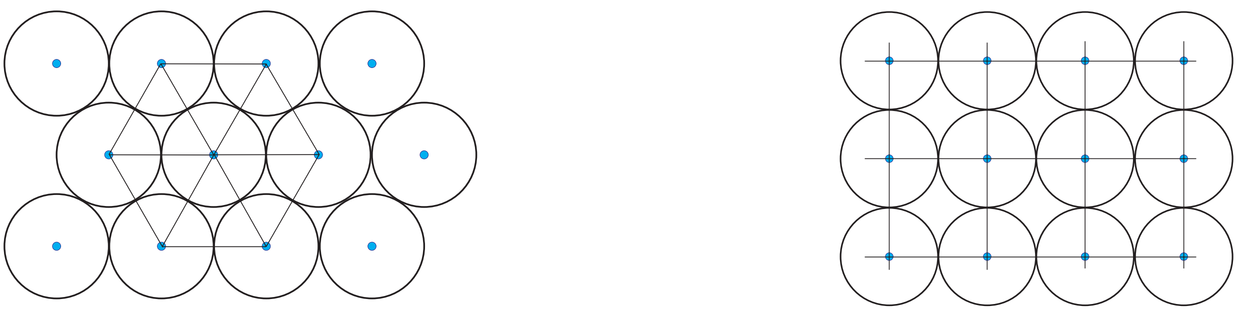


Figure 6-2 Speaker coverage with no overlap: hexagonal (left), square (right)

Minimum Overlap (spacing distance = $r\sqrt{2}$ for square pattern, $r\sqrt{3}$ for hex pattern): The coverage of each speaker overlaps adjacent speakers just enough to avoid any gaps in coverage, but no more (Figure 6-3). Minimum overlap performs much better than no overlap. The spacing depends on whether the speakers are in a square or hexagonal pattern.

Figure 6-3 Speaker coverage with minimum overlap: hexagonal (left), square (right)

Edge-to-Center (also called *center-to-center*; spacing distance = radius of the coverage area): The edge of each speaker's coverage area meets the center of adjacent speakers' coverage areas (Figure 6-4). This is the highest speaker density commonly used in distributed systems and gives the best performance. Where the room acoustics are poor or background noise is high, this spacing may be required for intelligible speech.

Figure 6-4 Speaker coverage with edge-to-center overlap: hexagonal (left), square (right)

Wall-Mount Speakers

NOTE: *Before considering a wall-mount installation, determine whether the construction will support the speakers and that the mounting hardware can be installed properly.*

The factors guiding the layout of wall-mount speakers are the same as for ceiling speakers: The area covered by each speaker, the evenness of coverage desired, and the client's budget. Calculating the coverage area, however, is more complex and less precise. In addition, the spacing is controlled by the designer only in one plane (along the wall), unless you have the luxury of specifying room dimensions in the sound system design. Aiming and setting the speaker's height is important and is guided by the room dimensions, especially the distance to the opposite wall (or to the farthest listeners).

Speaker Coverage Area

An approximate value for the coverage area of a speaker mounted to the wall and aimed at an off-angle to the floor can be obtained by projecting two triangles from the speaker to the listening plane, representing the horizontal and vertical coverage. In most instances, only half the rated vertical coverage angle should be used, with the speaker's central axis aimed at the farthest point to be covered. This results in a triangular coverage pattern that closely approximates the sound distribution from a wall-mounted speaker. It is important to bear in mind the effect of distance as well as speaker dispersion when calculating coverage. In the horizontal plane, the width of the coverage area is affected by the added distance from the speaker when moving off-axis along a line perpendicular to the coverage axis. The effective coverage angle is thus narrower than the speaker's rated coverage angle for purposes of calculating the coverage area and the spacing. In the vertical plane (or near-to-far), the depth of the coverage area is affected by the increasing proximity as the listener moves under the speaker. Thus, the effective vertical coverage is greater than the rated vertical coverage angle. Coverage areas for all of TOA's wall-mount speaker models are listed in Chapter 8: *Speaker Application Tables.*

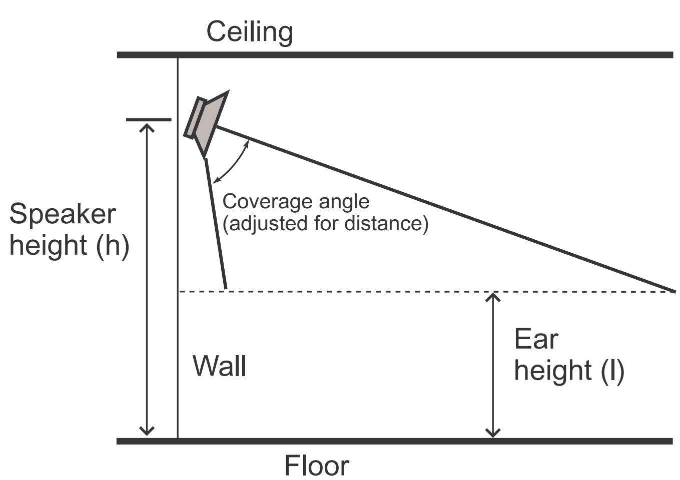


Figure 6-5 Wall-mount speaker coverage area

Speaker Spacing and Layout Pattern

Because of the triangular shape of the coverage area, wall-mount speakers work best when placed on facing walls and staggered so that each speaker is aimed at a point mid-way between two speakers on the opposite wall, at about ear level. The best spacing between speakers depends on their height and distance to the opposite wall. This is because the width of the triangular coverage area is proportional to its depth. Recommended spacings for all of TOA's wall-mount speaker models are listed in Chapter 8: *Speaker Application Tables.*

Subwoofers

To calculate the number of subwoofers needed, determine the maximum rated output of a single subwoofer (see *The Decibel* on page 17, and *Determining Maximum Output: Sensitivity and Power Handling* on page 21), and add a placement factor to this value (see below). Then add subwoofers until this level is 6–9 dB higher than the main speakers. To increase the distributed subwoofer level by 3 dB, double the number of subwoofers and the total power driving them.

Placement Factor: The placement of the subwoofers with respect to walls, floors, and other hard boundaries affects the system amplitude response. Compared to a subwoofer suspended in free air, a subwoofer next to one rigid wall increases its output 3–6 dB with the same power input, depending how close it is to the wall (the closer the better). A subwoofer located in a junction between two boundaries (two walls, one wall and floor or ceiling) increases its output 6–9 dB. A subwoofer located in the junction between three boundaries (two walls and the floor or ceiling) increases its output 9–15 dB (equivalent to increasing the input power by a factor of 8–30). Note the conditions under which the subwoofer was rated (i.e., *half-space*, which means against, or built into, one boundary), and when calculating maximum output, factor in the speaker placement in comparison to the measurement condition. For example, if the speaker was measured under half-space conditions, but will be used on the floor in a corner, then add 6–9 dB to the speaker's maximum output level.

Fraction-space loading can be described in greater detail as follows:

The maximum SPL of a subwoofer is increased by placing it against one or more boundaries. This effect, known as *bass* or *fraction-space loading*, begins to occur when the speaker is within 1/8 wavelength at a given frequency from the boundary, and increases the output 3–6 dB (depending on the actual distance) for each boundary. For example, at 100 Hz (wavelength = 11.3 ft), with the subwoofer positioned 2.825 ft from the floor, the level will be 3 dB higher than a subwoofer suspended in free air. A subwoofer flush-mounted onto the floor or a large wall (known as *half-space* loading) has a level 6 dB higher than if it were suspended in free air. Each additional boundary increases the output 3–6 dB. For example, placing the subwoofer at the junction of two boundaries (*quarter-space* loading) adds 6–12 dB; three boundaries (*eighth-space* loading) increases the output 9–15 dB. These boundaries must be massive and rigid enough to contain the wave front without flexing. Thin materials, such as curtains or temporary walls, will not produce this effect. The surfaces must be large enough to support the wavelength of the relevant frequencies; at least one wavelength of surface dimension is required to gain the full 6 dB increase.

Chapter 7: Amplifier Selection

Direct Connection or Constant Voltage

Installed sound systems commonly use either a *direct connection* (also called *low impedance*) or *constant voltage* (also called *high impedance*) amplifier/speaker interface. Direct connection to a low impedance amplifier allows up to two 8 Ω speakers to be safely driven without resorting to series-parallel wiring, which is inadvisable in most situations. To connect more than two speakers per amplifier channel, most distributed speaker systems use the constant voltage method.

Constant voltage speaker lines (i.e., 70.7 or 25 V) do not actually have constant voltage on them. Their line impedance is varied using transformers to achieve the same *theoretical maximum* voltage in any system. This approach makes it simple to design and scale systems as needed. Each system uses a step-up transformer on the output of the amplifier to raise its source impedance, and step-down transformers on each speaker to raise their load impedance. The speaker transformer load impedances are given in Watts (based on the rated line voltage) instead of Ohms, to simplify system set-up. In addition to making system design and expansion easier, constant voltage lines also dramatically reduce speaker cable costs, especially in large systems, by reducing the required thickness of cable for a given distance run. The following sections demonstrate the design of constant voltage systems.

Power Requirements

NOTE: *The term L_{req} will be used denote required level.*

Once the number and placement of speakers is decided, calculate the required amplifier power. First, calculate the power required per speaker using the following steps:

1. Determine the L_{req} including headroom for program peaks. Headroom is included by adding 6–10 dB above the expected operating level.
2. Find the speaker's sensitivity rating (SPL, 1 W @ 1 m) from the specifications list Chapter 8: *Speaker Application Tables*.
3. Use the chart for attenuation over distance (see Figure 5-1 on page 22), find the speaker's level at the listener with an input of 1 W (L_w) as follows: In the top half of the chart, find the distance from speaker to listener, then read the amount of attenuation (dB) from the bottom half of the chart. Subtract this amount from the sensitivity rating to get the level at the listener with 1 W input (L_w).
4. Subtract L_w from L_{req} to obtain the level increase needed above 1 W (dBW). If the difference is negative, it is safe to assume that dBW is zero.

5. Use the top half of the chart for level change with power input (see Figure 5-2 on page 22) to locate the point corresponding to the required level increase, or dBW. Next, read the power level from the bottom half of the chart. Then, using the speaker's specifications, select the speaker's smallest wattage tap that is greater than the power level indicated on the chart. This is the minimum power you need for each speaker.
6. After determining the power needed for each speaker, add them up to get the total speaker Wattage.

To allow for variations in transformer characteristics, it is a good practice to select an amplifier whose rated output is at least 120% of the speaker Wattage total. If the speakers are connected directly (in a 4 or 8 Ω system), the amplifier size should be at least equal to the speaker Wattage total.

Subwoofer Power Requirements

To get full value from subwoofers, we recommend supplying them with as much power as they can safely handle. The maximum continuous *pink noise* power rating is a good indicator of the *minimum* power to provide for a subwoofer. This amount can be doubled if the added power falls within budget. The subwoofer's maximum *program* (sometimes called *peak*) rating typically indicates the maximum power you should provide. Due to the nature of low frequency program material, there is much room for error in any general guidelines for subwoofers. The best method to insure the amplifier and subwoofer are matched is to listen to them together, using the same speaker location and program material that will be used in the final job.

Examples

High-Quality Paging System

A workspace needs reliable and intelligible paging in all areas, for both standing and seated listeners. The room is 30 x 40 ft with a 10 ft ceiling. TOA model F-121CM speakers are selected for their wide dispersion.

From the F-121CM's coverage and spacing table (page 37), we first refer to the row corresponding to the ceiling height for standing listeners (4 ft above listener height; h - l = 4). The spacing recommendations for this height range from 7–14 ft, depending on the desired uniformity of coverage. Using a square pattern with minimum overlap, the spacing between speakers is 10 ft, which works out to three rows of four speakers (12 speakers total).

Since the workspace will have a minimal noise level, the target operating level is set slightly above the base level (75 dB) for paging, at 78 dB, with 10 dB of headroom, for a L_{req} of 88 dB.

The F-121CM has a rated sensitivity of 90 dB, 1 W @ 1 m. The typical seated listener will be about 7–8 feet away from the nearest speaker. Using the attenuation with distance chart (see Figure 5-1 on page 22), this provides 82 dB with 1 W at the listener.

Using the level change with power input chart (see Figure 5-2 on page 22), we see that 4 W per speaker provides the 6 dB needed to reach the L_{req}. The speaker's smallest available transformer tap above 4 W is 5 W. Add the speakers at 5 W each to yield a total of 60 W. Multiply by 1.2 (120%) to get the minimum amplifier power: 72 W.

Outdoor Paging System

Paging is needed in an outdoor area. The area is 100 x 200 ft (20,000 sq. ft), and the speakers will be mounted on poles along the center of the area (200 ft). TOA model SC-615T is selected for its high efficiency and wide area coverage.

From the coverage depth column of the SC-615T coverage and spacing table (page 53), we see that mounting a speaker 10 ft above the listener's ear level and aiming it down by 10° results in a coverage area that extends 57 ft from the base of the speaker's mounting surface. This positioning allows reaching the edges of our outdoor area from poles along the center line.

When mounted 10 ft above ear level (approx. 16 ft high), the rated coverage area of the SC-615T is 1713 sq. ft, suggesting that 12 horns are needed to cover the space smoothly. Ideally, the horns should be mounted on the central poles, back-to-back, aiming outward.

Assume the measured noise levels in this outdoor setting are 70 dB (A-weighted). The operating level should be 90 dB, with 6–10 dB headroom, for a L_{req} of 96–100 dB.

From the SC-615Tcoverage and spacing table (page 53), we see that when mounted 10 ft above ear level and aimed down 10°, it delivers 99 dB SPL to the farthest on-axis listener, at 57 ft from the base of the speaker's mounting surface. This is based on operation at the maximum transformer tap of 15 W, and is within our target range. Adding 12 speakers at 15 W yields a speaker total of 180 W. Multiply by 1.2 (120%) for a minimum amplifier rating of 216 W.

To economize, we could lower the operating level to 96 dB. Using the level change with power input chart (see Figure 5-2 on page 22), we see that a drop of 3 dB reduces the power requirement by a factor of 2, for a minimum amplifier power of 108 W. Since this brings our headroom down to 6 dB, it is wise to use a paging mic input with built-in compression. This is a good idea for any paging system in noisy environments, but especially when headroom is limited. The TOA model M-61S input module performs this function when used with a 900 Series mixer or mixer/amplifier.

High-Quality Multi-Purpose System

A multi-purpose room needs high-quality sound for video and A/V presentations, speech reinforcement, and background music for company functions. The room is 40 x 80 ft with a 12 ft ceiling. TOA model F-121CM speakers are selected for their ability to meet the wide-ranging requirements.

From the F-121CM's coverage and spacing table (page 37), we see that spacing recommendations range from 10–21 ft for standing listeners (h – l = 6 ft.) and 14–28 ft for seated listeners (h – l = 8 ft). Selecting a square pattern and spacing the speakers at 20 ft intervals puts us within both ranges and allows a simple layout of two rows of four speakers (8 total).

To deliver convincing, distortion-free movie sound, the system should be designed for a maximum average level of 85 dB at the listeners, with 10 dB of headroom for transient peaks, for a L_{req} of 95 dB.

The F-121CM has a rated sensitivity of 90 dB, 1 W @ 1 m. Using the attenuation with distance chart (see Figure 5-1 on page 22), we find that this gives us 82 dB with 1 W at the listener.

Using the level change with power input chart (see Figure 5-2 on page 22), we see that 20 W per speaker provides the 13 dB to reach the L_{req}. Adding them up yields a speaker total of 160 W. Multiply by 1.2 (120%) to yield the minimum amplifier power: 192 W.

Chapter 8: Speaker Application Tables

How to Use This Section

This section is intended to serve as a quick reference to speed and ease system design. Keep in mind the following points to ensure best use of the tables.

All Speakers

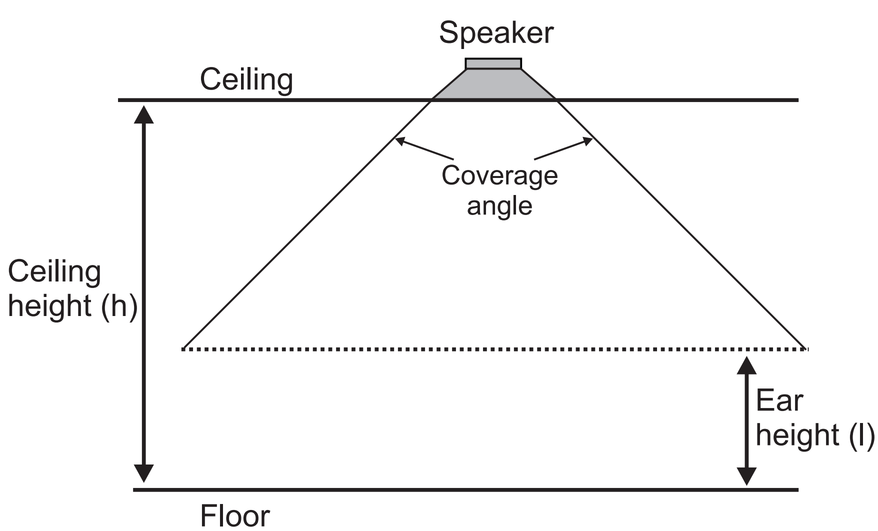
Speaker height is relative to listener height. If the value for *Height Above Listener* is 2, that means the speakers are placed 2 ft above the expected ear level of the listeners.

Coverage Area and *Spacing* recommendations are based on an adjusted estimate of coverage (averaged over the frequency range 1–4 kHz) that accounts for both speaker dispersion and listener distance relative to the speaker. This may make the numbers appear smaller than those found in other design guides but they will more accurately reflect real-world performance.

Maximum On-Axis SPL figures are based on operation at the highest transformer tap. Pink noise power capacity is used for speakers without transformers.

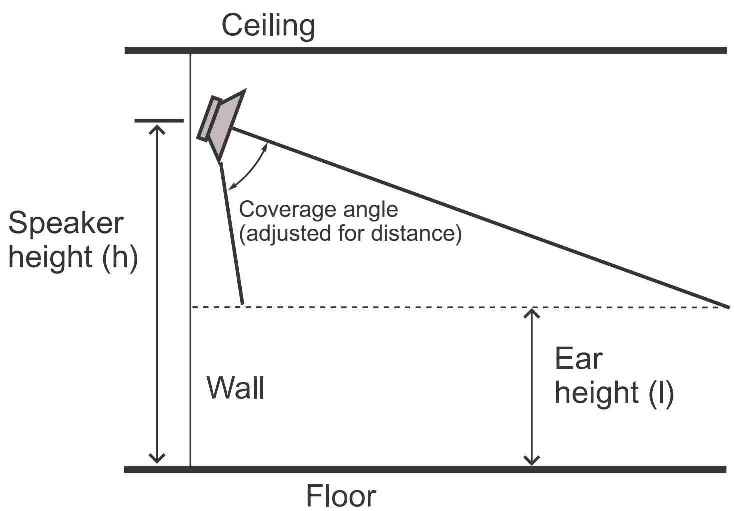
Ceiling Speakers

Spacing recommendations for ceiling speakers are based on the radius of the adjusted coverage area (as described in *Sound System Engineering*) except that in this guide, the term *Edge to Center* is used to describe the condition when the edge of one speaker's coverage overlaps up to the center of the next speaker's coverage (*center to center* spacing in *Sound System Engineering*).



Wall-mount Speakers

Spacing recommendations for wall-mounted speakers will vary dramatically depending on the height and aiming of the speakers, whether there is a facing wall, and how far away it is. When there is a facing wall up to 30 ft away, speakers should be staggered: speakers on one wall should be located and aimed mid-way between those on the opposite wall. If the facing wall is more than 30 ft away, we recommend using ceiling or other speakers to cover the center of the room to avoid echoes that degrade intelligibility. In outdoor areas, it is best to place speakers back-to-back, aimed outward when broad coverage is needed.



Downward Tilt refers to the number of degrees below horizontal the speaker is aimed.

Coverage Area is a very conservative estimate of the triangular area within which coverage will not vary more than ±3 dB (±4 dB where the downward tilt is 10°, due to the effects of distance), when averaged over the frequency range of 1–4 kHz.

Coverage Depth refers to the minimum, or perpendicular, distance between the far limit of the coverage area and the wall or surface that the speaker is mounted on. For best coverage, listeners should be no farther from the wall (pole, etc.) than this.

Maximum Spacing for Rated Coverage Depth: This number is equal to the width of the triangular coverage area at its wide end. The coverage area is this wide when the farthest listeners are a distance from the base of the speaker's mounting surface equal to the value of *Coverage Depth*. For example, if the *Coverage Depth* is 20 ft, and the *Edge to Edge Spacing* is 25 ft, then the far left corner of one speaker's coverage meets the far right corner of another speaker's coverage at a point 20 ft perpendicular from the wall on which the speakers are mounted. Maximum spacing should only be used indoors, when speakers are placed on two facing walls, and when the distance between the walls is approximately equal to the rated *Coverage Depth*. Closer spacing is needed if the walls are closer than the rated *Coverage Depth*.

Ceiling-mount Speakers

F-101C/M

F-101C/M Specifications	
Coverage Angle	120º H x 120º V
Frequency Response	80 Hz – 18 kHz
Sensitivity (1 W / 1 m)	90 dB
Power Handling	F-101CM: 20 W transformer F-101C: 40 W pink noise
Transformer Taps (F-101CM only)	70.7/100 V: 1, 3, 5, 10, 20 W
Components	4.7" driver
Installation Accessories (optional)	TBF-100 Tile Bridge, BBF-100 Back Box

F-101C/M Coverage And Spacing

Height Above Listener h-l (ft)	Coverage Area (sq. ft)	Spacing (ft)				
		Edge to Center Overlap	Min. Overlap (square)	Min. Overlap (hex)	No Overlap	Max. On-Axis SPL
2	13	2	3	3	4	107
3	28	3	4	5	6	104
4	50	4	6	7	8	101
5	79	5	7	9	10	99
6	113	6	8	10	12	98
8	201	8	11	14	16	95
10	314	10	14	17	20	93
12	452	12	17	21	24	92
14	616	14	20	24	28	90
16	804	16	23	28	32	89
18	1018	18	25	31	36	88
20	1257	20	28	35	40	87

F-121C/M

F-121C/M Specifications	
Coverage Angle	hemispherical
Frequency Response	80 Hz – 18 kHz
Sensitivity (1 W / 1 m)	90 dB
Power Handling	F-121CM: 20 W transformer F-121C: 40 W pink noise
Transformer Tap (F-121CM only)	70.7/100 V: 1, 3, 5, 10, 20 W
Components	4.7" driver with diffuser cone
Installation Accessories (optional)	TBF-100 Tile Bridge, BBF-100 Back Box
900 Series Equalizer Module	E-03R module or AC-120 stand-alone EQ

F-121C/M Coverage And Spacing

Height Above Listener h-l (ft)	Coverage Area (sq. ft)	Spacing (ft)				
		Edge to Center Overlap	Min. Overlap (square)	Min. Overlap (hex)	No Overlap	Max. On-Axis SPL
2	38	3	5	6	7	107
3	85	5	7	9	10	104
4	151	7	10	12	14	101
5	236	9	12	15	17	99
6	339	10	15	18	21	98
8	603	14	20	24	28	95
10	942	17	24	30	35	93
12	1357	21	29	36	42	92
14	1847	24	34	42	48	90
16	2413	28	39	48	55	89
18	3054	31	44	54	62	88
20	3770	35	49	60	69	87

PC-671R/RV

PC-671R/RV Specifications	
Coverage Angle	65º H x 65º V
Frequency Response	90 Hz – 16 kHz
Sensitivity (1 W / 1 m)	96 dB
Power Handling	6 W pink noise
Transformer Taps	25/70.7 V: 0.5, 1, 2, 3, and 6 W
Components	8" driver

PC-671R/RV Coverage And Spacing

Height Above Listener h-l (ft)	Coverage Area (sq. ft)	Spacing (ft)				
		Edge to Center Overlap	Min. Overlap (square)	Min. Overlap (hex)	No Overlap	Max. On-Axis SPL
2	5	1	2	2	3	108
3	11	2	3	3	4	105
4	20	3	4	4	5	102
5	32	3	5	6	6	100
6	46	4	5	7	8	99
8	82	5	7	9	10	96
10	128	6	9	11	13	94
12	184	8	11	13	15	93
14	250	9	13	15	18	91
16	326	10	14	18	20	90
18	413	11	16	20	23	89
20	510	13	18	22	25	88

H-1

H-1 Specifications	
Coverage Angle	120º H x 100º V
Frequency Response	120 Hz – 20 kHz
Sensitivity (1 W / 1 m)	85 dB
Power Handling	Transformer: 12 W 4 Ω Direct: 30 W pink noise
Transformer Taps	70.7/100 V: 3, 6, 12 W
Components	LF: 3" x 2" Neodymium HF: 3/4" Ferrofluid-cooled dome
Installation Accessories	HY-H1 pre-installation kit (optional)
900 Series Equalizer Module	E-04R

H-1 Coverage And Spacing (Ceiling Mount)

Height Above Listener h-l (ft)	Coverage Area (sq. ft)	Spacing (ft)				Max. On-Axis SPL
		No Overlap	Min. Overlap (square)	Min. Overlap (hex)	Edge to Center Overlap	
2	9	2	2	3	3	100
3	20	3	4	4	5	97
4	35	3	5	6	7	94
5	55	4	6	7	8	92
6	80	5	7	9	10	91
8	142	7	9	12	13	88
10	221	8	12	15	17	86
12	319	10	14	17	20	85
14	434	12	17	20	23	83
16	566	13	19	23	27	82
18	717	15	21	26	30	81
20	885	17	24	29	34	80

H-1 Coverage and Spacing (Wall Mount)					
Height Above Listener h-l (ft)	**Downward Tilt (degrees)**	**Coverage Area (sq. ft)**	**Coverage Depth (ft)**	**Maximum Spacing for Rated Coverage Depth (ft)**	**Max. SPL for Farthest On-Axis Listener (dB)**
2	10	124	11	23	85
3	10	280	17	35	82
4	10	498	23	46	79
5	10	778	28	58	77
4	20	124	11	23	85
5	20	194	14	29	83
6	20	280	16	35	81
8	20	498	22	47	79
10	20	778	27	58	77
8	30	233	14	32	82
10	30	364	17	40	80
12	30	524	21	48	79

H-2/WP

H-2/WP Specifications	
Coverage Angle	100º H x 60º V
Frequency Response	100 Hz – 20 kHz
Sensitivity (1 W / 1 m)	88 dB
Power Handling	Transformer: 12 W 4 Ω Direct: 30 W pink noise
Transformer Taps	70.7/100 V: 3, 6, 12 W
Components	LF: 4.7" Neodymium HF: 3/4" Ferrofluid-cooled dome
Weather-Resistant version	H-2WP
900 Series Equalizer Module	E-05R

H-2/WP Coverage And Spacing

h-l (ft)	Coverage Area (sq. ft)	Spacing (ft)				Max. On-Axis SPL
		No Overlap	Min. Overlap (square)	Min. Overlap (hex)	Edge to Center Overlap	
2	9	2	2	3	3	103
3	20	3	4	4	5	100
4	35	3	5	6	7	97
5	55	4	6	7	8	95
6	80	5	7	9	10	94
8	142	7	9	12	13	91
10	221	8	12	15	17	89
12	319	10	14	17	20	88
14	434	12	17	20	23	86
16	566	13	19	23	27	85
18	717	15	21	26	30	84
20	885	17	24	29	34	83

Wall-mount Speakers

BS-1030B/W

BS-1030B/W Specifications	
Coverage Angle	100º H x 100º V
Frequency Response	80 Hz – 20 kHz
Sensitivity (1 W / 1 m)	90 dB
Power Handling	Transformer: 30 W 8 Ω Direct: 30 W pink noise
Transformer Taps	70.7/100 V: 5, 10, 15, 20, 30 W
Components	LF: 4.7" cone HF: 1" balanced-dome
Installation Accessories	Mounting bracket included WCB-12/W swivel bracket (optional)

BS-1030B/W Coverage and Spacing

Height Above Listener h-l (ft)	Downward Tilt (degrees)	Coverage Area (sq. ft)	Coverage Depth (ft)	Maximum Spacing for Rated Coverage Depth (ft)	Max. SPL for Farthest On-Axis Listener (dB)
2	10	103	11	19	94
3	10	231	17	29	90
4	10	410	23	39	88
5	10	641	28	48	86
4	20	101	11	20	94
5	20	158	14	25	92
6	20	227	16	29	90
8	20	404	22	39	88
10	20	631	27	49	86
8	30	186	14	27	91
10	30	291	17	34	89
12	30	419	21	40	87

BS-20W/WHT

BS-20W/WHT Specifications	
Coverage Angle	30º H x 90º V
Frequency Response	100 Hz – 20 kHz
Sensitivity (1 W / 1 m)	94 dB
Power Handling	20 W
Transformer Taps	70.7/100 V: 5, 10, 15, 20 W
Components	LF: 5.25" cone HF: CD horn and piezo
Installation Accessories	Mounting bracket included

BS-20W/WHT Coverage and Spacing

Height Above Listener h-l (ft)	Downward Tilt (degrees)	Coverage Area (sq. ft)	Coverage Depth (ft)	Maximum Spacing for Rated Coverage Depth (ft)	Max. SPL for Farthest On-Axis Listener (dB)
2	10	103	11	19	96
3	10	231	17	29	93
4	10	410	23	39	90
5	10	641	28	48	88
4	20	101	11	20	96
5	20	158	14	25	94
6	20	227	16	29	92
8	20	404	22	39	90
10	20	631	27	49	88
8	30	186	14	27	93
10	30	291	17	34	91
12	30	419	21	40	90

CS-64, CS-154, CS-304

CS Series Specifications			
	CS-64	**CS-154**	**CS-304**
Coverage Angle (2 kHz)	100º H x 100º V	110º H x 85º V	110º H x 85º V
Frequency Response	130 Hz – 13 kHz	150 Hz – 15 kHz	120 Hz – 15 kHz
Sensitivity (1 W / 1 m)	96 dB	97 dB	98 dB
Power Handling (transformer)	6 W	15 W	30 W
Transformer Taps	70.7 V: 0.5, 1.5, 3, 6 W 100 V: 1, 3, 6 W	70.7 V: 2.5, 7.5, 15 W 100 V: 5, 10, 15 W	70.7 V: 5, 10, 15, 30 W 100 V: 10, 20, 30 W
Components	4.7" Full-range, weather-resistant treated cone	4.7" Full-range, weather-resistant treated cone	4.7" Full-range, weather-resistant treated cone
Installation Accessories	Stainless steel mounting bracket included	Stainless steel mounting bracket included	Stainless steel mounting bracket included

CS-64 Coverage and Spacing					
Height Above Listener h-l (ft)	**Downward Tilt (degrees)**	**Coverage Area (sq. ft)**	**Coverage Depth (ft)**	**Maximum Spacing for Rated Coverage Depth (ft)**	**Max. SPL for Farthest On-Axis Listener (dB)**
2	10	74	11	15	93
3	10	166	17	22	90
4	10	296	23	29	87
5	10	462	28	37	85
4	20	70	11	15	93
5	20	109	14	19	91
6	20	156	16	22	89
8	20	278	22	30	87
10	20	435	27	37	85
8	30	123	14	20	90
10	30	192	17	25	88
12	30	277	21	31	87

CS-154 Coverage and Spacing					
Height Above Listener h-l (ft)	**Downward Tilt (degrees)**	**Coverage Area (sq. ft)**	**Coverage Depth (ft)**	**Maximum Spacing for Rated Coverage Depth (ft)**	**Max. SPL for Farthest On-Axis Listener (dB)**
3	10	258	17	35	95
4	10	458	23	46	92
5	10	716	28	58	90
6	10	1031	34	69	89
8	10	1832	45	92	86
10	10	2863	57	115	84
6	20	240	16	35	94
8	20	427	22	47	92
10	20	667	27	58	90
12	20	960	33	70	88
14	20	1307	38	82	87
16	20	1707	44	94	86
10	30	293	17	40	93
12	30	422	21	48	92
14	30	574	24	56	90
16	30	750	28	64	89
18	30	949	31	72	88

CS-304 Coverage and Spacing					
Height Above Listener h-l (ft)	**Downward Tilt (degrees)**	**Coverage Area (sq. ft)**	**Coverage Depth (ft)**	**Maximum Spacing for Rated Coverage Depth (ft)**	**Max. SPL for Farthest On-Axis Listener (dB)**
4	10	384	23	39	96
5	10	601	28	48	94
6	10	865	34	58	93
8	10	1537	45	77	90
10	10	2402	57	97	88
8	20	358	22	39	96
10	20	560	27	49	94
12	20	806	33	59	92
14	20	1097	38	69	91
16	20	1433	44	79	90
10	30	246	17	34	97
12	30	354	21	40	96
14	30	482	24	47	94
16	30	629	28	54	93
18	30	796	31	60	92
20	30	983	35	67	91
22	30	1189	38	74	90

F-160G/W, F-240G/W

F-160/F-240 Specifications		
	F-160	**F-240**
Coverage Angle	90º H x 90º V	90º H x 90º V
Frequency Response	100 Hz – 20 kHz (1/2- or 1/4-space)	65 Hz – 20 kHz (1/2- or 1/4-space)
Sensitivity (1 W / 1 m)	91 dB	92 dB
Power Handling	30 W (F-160GM/WM) 50 W pink noise (F-160G/W)	30 W (F-240GM/WM) 50 W pink noise (F-240G/W)
Transformer Taps (F-160GM/WM, F-240GM/WM only)	70.7 V: 2.5, 5, 10, 15, 30 W 100 V: 5, 10, 20, 30 W	70.7 V: 2.5, 5, 10, 15, 30 W 100 V: 5, 10, 20, 30 W
Components	LF: 5.25" HF: 1" Dome	LF: 6.5" HF: 1" Dome
Installation Accessories	WCB-12/W swivel bracket	CMB-31W, WCB-24/W swivel bracket

F-160/F-240 Coverage and Spacing					
Height Above Listener h-l (ft)	**Downward Tilt (degrees)**	**Coverage Area (sq. ft)**	**Coverage Depth (ft)**	**Maximum Spacing for Rated Coverage Depth (ft)**	**Max. SPL for Farthest On-Axis Listener (dB) F-160/F-240**
2	10	113	11	21	95 / 96
3	10	254	17	32	92 / 93
4	10	452	23	42	89 / 90
5	10	707	28	53	87 / 88
4	20	112	11	21	95 / 96
5	20	175	14	27	93 / 94
6	20	252	16	32	91 / 92
8	20	449	22	43	89 / 90
10	20	701	27	54	87 / 88
8	30	208	14	29	92 / 93
10	30	325	17	37	90 / 91
12	30	469	21	44	89 / 90

F-505G/W, F-605G/W

F-505/F-605 Specifications		
	F-505G/W	**F-605G/W**
Coverage Angle	60º H x 40º V	60º H x 40º V
Frequency Response	70 Hz – 20 kHz	65 Hz – 20 kHz
Sensitivity (1 W / 1 m)	93 dB	98 dB
Power Handling	80 W pink noise	80 W pink noise
Impedance	8 Ω	8 Ω
Components	LF: 8" HF: CD horn and compression driver	LF: 12" HF: CD horn and compression driver
Installation Accessories	HY-30/W, HY-501B/W	HY-30/W, HY-601B/W

F-505/F-605 Coverage and Spacing					
Height Above Listener h-l (ft)	**Downward Tilt (degrees)**	**Coverage Area (sq. ft)**	**Coverage Depth (ft)**	**Maximum Spacing for Rated Coverage Depth (ft)**	**Max. SPL for Farthest On-Axis Listener (dB) F-505/F-605**
4	10	268	23	27	95 / 100
6	10	603	34	40	92 / 97
8	10	1071	45	53	89 / 94
10	10	1674	57	66	87 / 92
12	10	2410	68	80	86 / 91
8	20	252	22	27	95 / 100
10	20	394	27	34	93 / 98
12	20	567	33	41	91 / 95
14	20	772	38	47	90 / 95
16	20	1008	44	54	89 / 94
18	20	1276	49	61	88 / 93
20	20	1575	55	68	87 / 92
20	30	698	35	46	90 / 95
24	30	1005	42	55	89 / 94

H-3/WP

H-3/WP Specifications	
Coverage Angle	140º H x 70º V
Frequency Response	100 Hz – 20 kHz
Sensitivity (1 W / 1 m)	89 dB
Power Handling	Transformer: 30 W 8 Ω Direct: 50 W pink noise
Transformer Taps	70.7 V: 3.75, 7.5, 15, 30 W 100 V: 7.5, 15, 30 W
Components	LF: Two 4" Neodymium HF: 1" Dome
Installation Accessories	Wall-mounting plate included
900 Series Equalizer Module	E-06R (optional)

H-3/WP Coverage and Spacing

Height Above Listener h-l (ft)	Downward Tilt (degrees)	Coverage Area (sq. ft)	Coverage Depth (ft)	Maximum Spacing for Rated Coverage Depth (ft)	Max. SPL for Farthest On-Axis Listener (dB)
2	10	133	11	27	93
3	10	298	17	41	90
4	10	531	23	55	87
5	10	829	28	69	85
4	20	121	11	28	93
5	20	189	14	35	91
6	20	272	16	42	89
8	20	484	22	56	87
10	20	756	27	70	85
8	30	209	14	38	90
10	30	326	17	48	88
12	30	470	21	57	87

Paging Horns

SC-610/T, SC-615/T, SC-630/T, SC-650

SC Series Specifications				
	SC610/T	SC615/T	SC630/T	SC650
Coverage Angle	70º H x 100º V	70º H x 90º V	55º H x 70º V	55º H x 45º V
Frequency Response	315 Hz – 12.5 kHz	280 Hz – 12.5 kHz	250 Hz – 10 kHz	250 Hz – 6 kHz
Sensitivity (1 W / 1 m)	110 dB	112 dB	113 dB	108 dB
Power Handling	10 W	15 W	30 W	50 W
Transformer Taps	70.7 V: 0.5, 1.5, 3, 6 W 100 V: 1, 3, 6 W	70.7 V: 2.5, 7.5, 15 W 100 V: 5, 10, 15 W	70.7 V: 5, 10, 15, 30 W 100 V: 10, 20, 30 W	not applicable
Components	Phenolic diaphragm compression driver	Phenolic diaphragm compression driver	Phenolic diaphragm compression driver	Phenolic diaphragm compression driver
Installation Accessories	Stainless steel mounting bracket included	Stainless steel mounting bracket included	Stainless steel mounting bracket included	Stainless steel mounting bracket included

SC-610/T Coverage and Spacing					
Height Above Listener h-l (ft)	**Downward Tilt (degrees)**	**Coverage Area (sq. ft)**	**Coverage Depth (ft)**	**Maximum Spacing for Rated Coverage Depth (ft)**	**Max. SPL for Farthest On-Axis Listener (dB)**
4	10	282	23	27	103
5	10	441	28	33	101
6	10	635	34	40	100
8	10	1129	45	53	97
10	10	1765	57	66	95
12	10	2541	68	80	94
8	20	278	22	27	103
10	20	434	27	34	101
12	20	625	33	41	99
12	30	288	21	28	103
16	30	512	28	37	100
20	30	800	35	46	98

SC-615/T Coverage and Spacing					
Height Above Listener h-l (ft)	**Downward Tilt (degrees)**	**Coverage Area (sq. ft)**	**Coverage Depth (ft)**	**Maximum Spacing for Rated Coverage Depth (ft)**	**Max. SPL for Farthest On-Axis Listener (dB)**
4	10	274	23	27	107
6	10	617	34	40	104
8	10	1096	45	53	101
10	10	1713	57	66	99
12	10	2466	68	80	98
14	10	3357	79	93	96
16	10	4384	91	106	95
18	10	5549	102	120	94
10	20	411	27	34	105
12	20	591	33	41	103
14	20	805	38	47	102
16	20	1051	44	54	101
18	20	1330	49	61	100
20	20	1642	55	68	99
16	30	473	28	37	104
20	30	739	35	46	102
24	30	1064	42	55	101

SC-630/T Coverage and Spacing					
Height Above Listener h-l (ft)	**Downward Tilt (degrees)**	**Coverage Area (sq. ft)**	**Coverage Depth (ft)**	**Maximum Spacing for Rated Coverage Depth (ft)**	**Max. SPL for Farthest On-Axis Listener (dB)**
6	10	467	34	32	108
8	10	830	45	43	105
10	10	1298	57	54	103
12	10	1869	68	64	102
14	10	2543	79	75	100
16	10	3322	91	86	99
18	10	4204	102	97	98
20	10	5190	113	107	97
22	10	6280	125	118	96
10	20	296	27	27	109
12	20	426	33	33	107
14	20	580	38	38	106
16	20	757	44	44	105
18	20	959	49	49	104
20	20	1183	55	55	103
20	30	510	35	37	106
24	30	735	42	45	105

SC-650 Coverage and Spacing					
Height Above Listener h-l (ft)	**Downward Tilt (degrees)**	**Coverage Area (sq. ft)**	**Coverage Depth (ft)**	**Maximum Spacing for Rated Coverage Depth (ft)**	**Max. SPL for Farthest On-Axis Listener (dB)**
6	10	422	34	32	105
8	10	751	45	43	102
10	10	1173	57	54	100
12	10	1689	68	64	99
14	10	2299	79	75	97
16	10	3003	91	86	96
18	10	3800	102	97	95
20	10	4692	113	107	94
22	10	5677	125	118	93
10	20	250	27	27	106
12	20	360	33	33	104
14	20	489	38	38	103
16	20	639	44	44	102
18	20	809	49	49	101
20	20	999	55	55	100
20	30	408	35	37	103
24	30	588	42	45	102

Appendix A: Wire Size Charts

Table 1 Speaker Cable Lengths (ft) and Gauges (AWG) for 70.7 V Line with 1 dB Power Loss

70.7 V	Wire Gauge (AWG)	10	12	14	16	18	20	22
Load Power (W)	Load Impedance (Ω)	Maximum Cable Distance (ft)						
10	490	*	*	*	7,200	4,600	2,800	1,800
15	327	*	*	7,600	4,800	3,000	1,920	1,200
20	245	*	9,200	5,600	3,600	2,200	1,400	900
30	163	10,000	6,200	3,800	2,400	1,500	960	600
40	122	7,400	4,600	2,800	1,800	1,100	700	450
60	81	5,000	3,200	1,900	1,200	730	480	**
100	49	2,900	1,820	1,120	720	230	**	**
200	24.5	1,450	910	560	360	110	**	**
400	12.2	730	460	280	180	**	**	**

Table 2 Speaker Cable Lengths (ft) and Gauges (AWG) for 25 V Line with 1 dB Power Loss

25 V	Wire Gauge (AWG)	10	12	14	16	18	20	22
Load Power (W)	Load Impedance (Ω)	Maximum Cable Distance (ft)						
10	61	3,700	2,300	1,400	900	575	350	225
15	41	2,500	1,550	950	600	375	240	150
20	31	1,850	1,150	700	450	275	175	113
30	20	1,250	775	475	300	188	120	**
40	15	925	575	350	225	138	**	**
60	10	625	400	238	150	**	**	**
100	6	363	228	140	90	**	**	**
200	3	181	114	70	**	**	**	**

* Greater than 10,000 feet

** Not recommended, may exceed safe current capacity of wire

Appendix B: Speaker Mounting Hardware and Accessory Reference

Model	Mounting Hardware	Accessories
BS-1030B/W	Ceiling/Wall-Mount Bracket included **WCB-12/W** Ceiling/Wall-Mount Bracket (optional)	
BS-20W/WHT	Ceiling/Wall-Mount Bracket included	
F-101C/M	**BBF-100** Back-box (requires TBF-100) **TBF-100** Tile-bridge	
F-121C/M	**BBF-100** Back-box (requires TBF-100) **TBF-100** Tile-bridge	**E-03R** 900 Series EQ Module **AC-120** Dual Channel Rack-Mount Processor
F-160G/W/M	**WCB-12/W** Ceiling/Wall-Mount Bracket	
F-160WP	**YS-150WP** Ceiling/Wall-Mount Bracket	
F-240G/W/M	**CMB-31/W** Ceiling-Mount Bracket **WCB-24/W** Wall-Mount Bracket (Economy) **WCB-31/W** Wall-Mount Bracket	
F-505G/W	**HY-30/W** Ceiling-Mount Bracket **HY-501B/W** Wall-Mount Bracket	
F-505WP/-L	**HY-30/W** Ceiling-Mount Bracket **HY-501B/W** Wall-Mount Bracket **YS-500** Pole/Wall-Mount Bracket (requires YS-60B for pole-mounting) **YS-60B** Pole bands	
F-605G/W	**HY-30/W** Ceiling-Mount Bracket **HY-601B/W** Wall-Mount Bracket	
F-605WP/-L	**HY-30/W** Ceiling-Mount Bracket **HY-601** Wall-Mount Bracket **YS-600** Pole/Wall-Mount Bracket (requires YS-60B for pole-mounting) **YS-60B** Pole bands	
FB-100	Six rigging points on enclosure (mounting hardware supplied by others).	**E-07S** 900 Series Low-Pass-Filter Module **MT-S0601** Matching Transformer
H-1	Mounting hardware included (see installation manual for details) **HY-H1** Wall-Mount Bracket also available separately for pre-construction (included w/ H-1). Note: Also fits RACO 953 gang-box, supplied by others, not required for installation.	**E-04R** 900 Series EQ Module
H-2/WP	Mounting hardware included (see installation manual for details)	**E-05R** 900 Series EQ Module
H-3/WP	Mounting hardware included (see installation manual for details)	**E-06R** 900 Series EQ Module
HB-1	Mounting hardware included (see installation manual for details)	**E-07S** 900 Series Low Pass-Filter Module **MT-S0601** Matching Transformer
PC-671R/RV	Back-box, tile-bridge, and rails (supplied by others)	

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