

## Application Note

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Training paper on designing distributed audio systems for homes and small offices.



# **Residential Distributed Audio Wiring Practices**

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## Abstract

This paper shall cover the basics of pre-wiring a residential distributed audio entertainment system. Such a system shall deliver high quality, stereo audio to various rooms or areas (also known as "zones") throughout the residence. Distributed Audio (sometimes referred to as "Whole-House" or "multi-room" audio) should not be confused with Home Theater, which is generally confined to reproducing audio soundtracks in a single room dedicated to viewing. Home Theater specifics are too complex to be adequately covered by this document. It should be assumed that the practices described within this document are generic. All installations must comply with local building codes and practices.

# Home Audio Concepts and Owner Expectations

## Out with the old...

The idea of distributing sound around the home is almost as old as sound reproduction itself. For many years, high-end homes had intercom systems with a music feature built-in. Although this "canned" music, because it was usually reproduced throughout the home on commercial-grade speakers using sources such as radio or audio cassette, did not approach high-fidelity standards, it was sufficient for many consumers, especially as there were few other options available at a reasonable cost.

## In with the new...

In the last several decades, things have changed dramatically. Home component stereo systems and high-end automotive music systems have created a consumer base that is not easily satisfied with "elevator" sound. They expect high quality stereo sound, and they do not want to have large speakers and amplifiers in every room to get it. The invention of the cheap, mass reproducible digital CD, combined with dramatic reductions in cost of CD players, multi-disc changers and "mega-disc" jukeboxes, has fueled a great demand for high quality music reproduction. Additional developments including high-quality in-wall versions of name-brand bookshelf and floor standing speakers, reliable audio controls, and relatively cheap amplifier power have combined to form a residential installed entertainment industry that is replacing those intercom music systems with high fidelity foreground music systems.

## Designing the Audio System You Desire

It is important that considerations are given to the installation of this type of system as early in the construction or remodel process as possible. Walk through the home with the owner or builder with the building plans to discuss how each room is expected to be used. Speaker and volume control placement issues should be resolved before beginning the pre-wire phase.

### The main components in distributed residential audio today are...

**Audio Source** - The most common source is a multi-disc CD player, CD jukebox or DVD changer, although distributing digital audio (MP3s or IP radio) from a computer or multimedia server represents an emerging application and a new challenge.

**Amplifier** - This can be as simple as using the "B" side of the customers existing A/V receiver. However, it is highly recommended that a separate receiver be used for maximum flexibility. This can be a basic unit, and does not need to be a new one. Many consumers have an older receiver stored away from when they upgraded to surround sound and may wish to use these for the whole-house audio amplifier. This is an excellent solution, provided the older unit is in good operating condition. In more ambitious systems, one option is a purpose-built multi-room amplifier with special features for whole-house distribution such as multiple channels (4-12) along with equalization, music-sensing and auto shut-off circuitry.

**Distribution scheme** - The distribution sub-system includes the cabling and any bridging, signal amplification or processing, and impedance matching equipment. The number of zones that a distribution scheme can support depends directly on the impedance matching system used. For standard impedance matching analog volume controls, the best practice is to limit the number of zones to eight. However, up to 32 zones could be installed on one amplifier with some compromise in overall system performance due to current limiting from the excessive load. Large distribution systems suffer from an apparent reduction in power to the speakers proportional to the size of the system. *(For information on selecting Speaker cables, see Appendix I)*

**Volume Controls** - Devices to control the volume in each room (zone) are what make the system accessible and useable. Every zone must have a means of adjusting the volume independently from the other zones in the home. Many volume controls, including selected Leviton controls, incorporate impedance matching into their feature sets.

**Speakers** - The speaker choices available to the installer are many—they include rectangular in-walls resembling bookshelf speakers, round ceiling speakers with multiple drivers, in-wall subwoofers, "utility" mini-speakers on brackets for indoor and outdoor applications, specialized camouflaged speakers for patios and gardens, and much more. The homeowner will most likely have a set preference from the beginning. When selecting speakers, keep the following criteria in mind:

1. **Aesthetics** - The physical appearance of a speaker in the room is perhaps the most important consideration. The speakers must fit the overall décor and use of the room. Do not attempt to place large wall mounted speaker boxes in a dining room for instance. Flush mounted speakers in the ceiling are far less obtrusive.

2. **Dispersion** - Select a speaker that can be installed in such a way as to give the customer maximum stereo sound coverage. Ceiling speakers offer the best coverage in most applications. Wall mounted speakers, either flush or surface, can work well in areas with low ceilings or rooms with major ceiling features that draw attention upward such as a chandelier.
3. **Sensitivity and Room Size** - Balance is the key to a quality sound system installation. Large rooms, such as living rooms, typically have acoustically challenging problems. These rooms have soft, sound absorbing furniture and carpets that effectively attenuate music volume. The opposite is true of small spaces like a bathroom. There an installer is likely to find hard surfaces everywhere including the floor. Music will sound much louder in a space like a bathroom or utility room. When installing speakers, keep in mind that spaces that are considerably larger than other spaces in the house may require additional speakers to offer smooth coverage and balanced sound levels. Sometimes smaller spaces actually require more speakers as well—such as in rooms with low ceilings using ceiling speakers, which, because of their relatively short distance from the listener, may not have enough space to properly disperse and attain even coverage. Also, when testing the system after installation, be sure to set the amplifier level such that low volume can be enjoyed in the small spaces while leaving enough room for the larger spaces to achieve high volume.

In any room, bear in mind that sound propagation is very similar to light (angle of incidence equals angle of reflection, for example). An advanced system designer can use this information to make a room "sound" larger or more intimate, much the same way a lighting designer uses lighting to define a room's ambience and establish comfort.

## Speaker and Volume Control Location Considerations

There is both art and science to the placement and installation of speakers for multi-room stereo systems. In foreground music applications, it is usually best to place the speakers in the room in such a way as to provide stereo left and right imaging when facing the main feature of the room. This feature could be a large picture window or fireplace in a general use space, an entertainment center or armoire in a living room, a centralized cooking area in a kitchen, etc. In a bedroom, the speakers are best placed over the foot of the bed. In background music applications, speakers installed in the ceiling usually provide the best dispersion in any space.

### Generally, speakers should...

1. Face the typical sitting location of the listeners
2. Be located in the room in such a way as to provide stereo left and right imaging when facing the main feature of the room or on the long wall of a room if the main feature is unknown.

Once the best scenario for speaker mounting has been selected, the rule-of-thumb is to mentally divide the room into three equal sections. The imaginary lines where any two sections meet are the best locations for the speakers (after taking into account furnishings, fireplaces, windows, and light fixtures). This method places the speakers roughly equidistant from the room corners (called boundaries), from each other and from the primary listening location. Placing a speaker too close to a room boundary can result in "doubling," or an excessively boomy sound. The wall/ceiling interface is another room boundary.

Try to keep speakers at least 2" (24") from any room boundary, including the ceiling. The exceptions are soffit locations, where there might be a protrusion of a drywall space into the room. Because soffits represent extruded room boundaries, they can sometimes be used to the installer's advantage. Soffits also can include an archway, such as the one sometimes found between a living room and dining room, around a built-in fireplace or even under a stairwell. Often these built-in cavities can optimize an in-wall speaker and should be used whenever possible.

A good practice is to have the speaker arrangement and listening area approximately in an equilateral triangle. Today's sophisticated A/V receivers and audio processors can help correct some room-speaker interaction problems, but it is better to start from as sonically-correct a placement as possible.

## A Word about Home Theater

Home Theater is one of the most commonly requested audio features in a new home. This system is different and usually separate from distributed audio systems. However, a Home Theater system may share common source components with a distributed audio system such as CD and DVD changers, satellite TV receivers, etc.. A Home Theater's A/V receiver can even be used to drive a distributed audio system if it is equipped with multi-room/multi-source capability. But for optimum results, Home Theaters operate best with dedicated control and amplification components since they are intended to operate in a specific room. This system also needs to be covered in the early walk through of the home. Pre-wiring speaker locations for Home Theater is more difficult, however, due to the importance of speaker placement in reference to the seating locations. For more information on Home Theater, see <http://www.hometheateradvice.com/>

# Pre-Wiring Models

The following best practice wiring method for home audio is intended to cover the majority of current and near future technologies and will ensure compliance with the current TIA/EIA 570-A.3 standard. There are, of course, many other possibilities designed around specific manufacturers and their equipment. This study, if followed, will give the installer and customer the widest choice possible in selecting equipment. This will allow budget maintenance now while keeping the option of future upgrades open.

There are three distinct wire runs in this system, with multiples of each to create a layout to suit the home. Figure 1 shows an example of this layout in a typical home. The three runs are:

**From the amplifier location to the distribution device.** From a suitable wallplate located at the amplifier's and source equipment location, run six conductors (3 pairs) of speaker wire and one Category 5 or 5e cable. Four of the speaker wire conductors (2 pairs) are to deliver left and right speaker signal to the distribution device, the remaining two conductors (pair) may be used to deliver DC voltage to the distribution device for switching or control. The Category 5 or 5e cable will support other communications relevant to audio distribution such as IR, data communications, A/V distribution, etc.

**From the distribution device to the volume control locations.** From the distribution device to each volume control location, pull four conductors (2 pairs) of speaker wire and one Category 5 or 5e cable to each volume control location. It is important to know that most volume controls (and their associated speaker wiring) are bulky arrangements that do not fit well into the average single gang electrical box. Low voltage rings (or mud rings) are a must if allowed by local code. The other alternative is to use the largest, deepest four square box available with the appropriate mud ring attached.

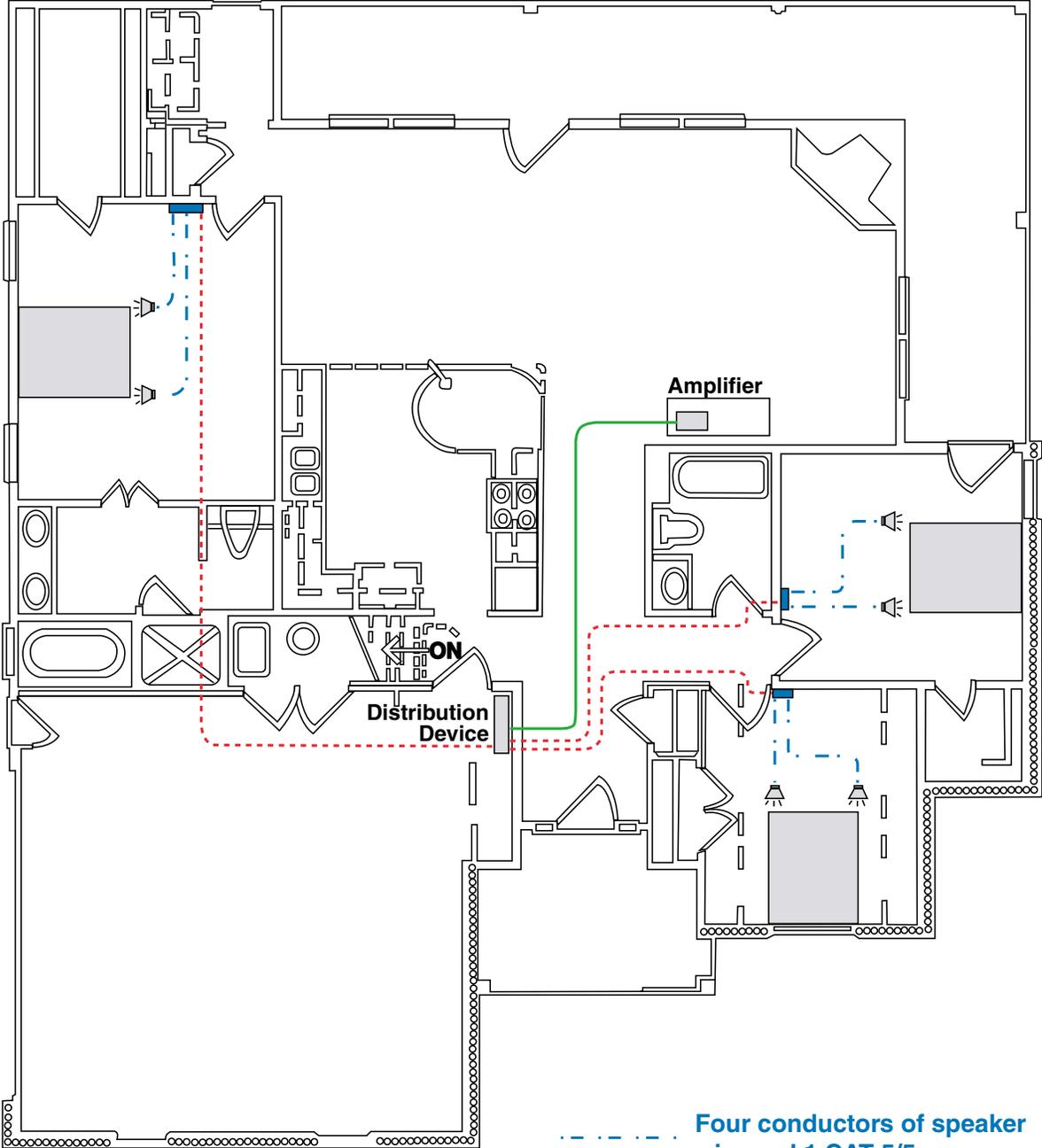
Each audio zone requires at least one volume control. Some systems, such as the Leviton Chopin® Digital Volume Control System, can have more than one control location, similar to a 3-way lighting circuit.

**From the volume control locations to the speakers.** From each volume control location to each speaker to be controlled by its associated volume control, pull two conductors (1 pair) of speaker wire and one Category 5 or 5e cable. Each speaker will require two conductors of speaker wire from the speaker to its associated volume control at a minimum. The Category 5 or 5e cable will support applications such as infrared repeating, keypads, displays, or the installation of amplified speakers.

## Options

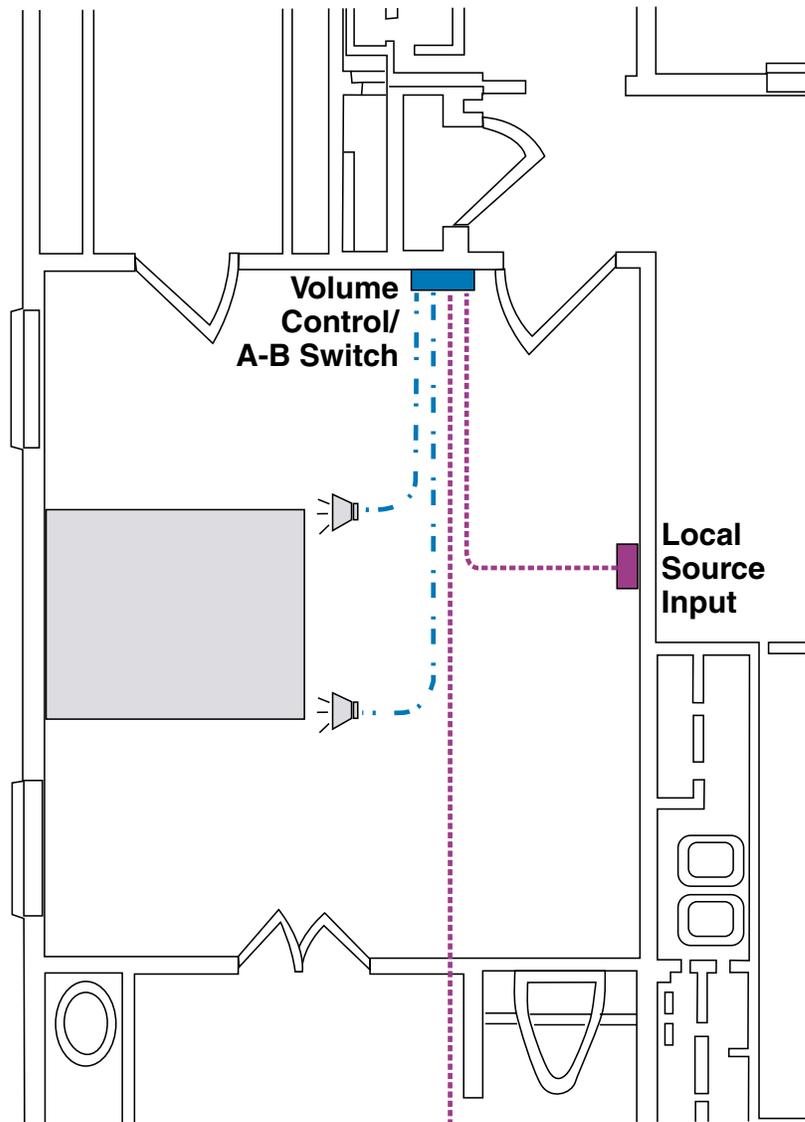
1. **Local source** - A common assumption is that the installed speakers in a given room could be hooked up to the TV or stereo that is also in the room. A simple solution is available to the installer to meet this need. Figure 2 shows the master bedroom of the floor plan shown earlier. To the standard setup, this installer has added a local source input. Depending on the audio system installation, either the speaker wire or the Category 5 or 5e wire will be used to deliver audio signal from the TV to the volume control. This will offer a dramatic improvement in audio over the small speakers in most televisions. The most commonly used system for this scenario is a small amplifier at the TV location and an A/B switch installed in a dual-gang mud ring with the volume control. See Figure 3 for a detail of this layout.
2. **Satellite entertainment systems** - Many consumers are buying mini-systems, high-end table radios and even portables to bring music to different rooms in the home. Most of these units feature line-level (RCA) inputs, and some even have audio/video and surround-sound capability (such as bedroom mini-systems). Networking these satellite audio/video systems to a centralized media source (such as a CD jukebox, DVD changer or even a PC for MP3 and internet radio) is much like networking computers—it requires dedicated wallplates and either 1. shielded cabling and a distribution amplifier or 2. one of the next-generation A/V media distribution packages that can distribute audio/video signals over Category 5 communications cabling to multiple satellite locations.

**Figure 1: Whole-House Example**



- Four conductors of speaker wire and 1 CAT 5/5e
- Four conductors of speaker wire and 1 CAT 5/5e
- Six conductors of speaker wire and 1 CAT 5/5e

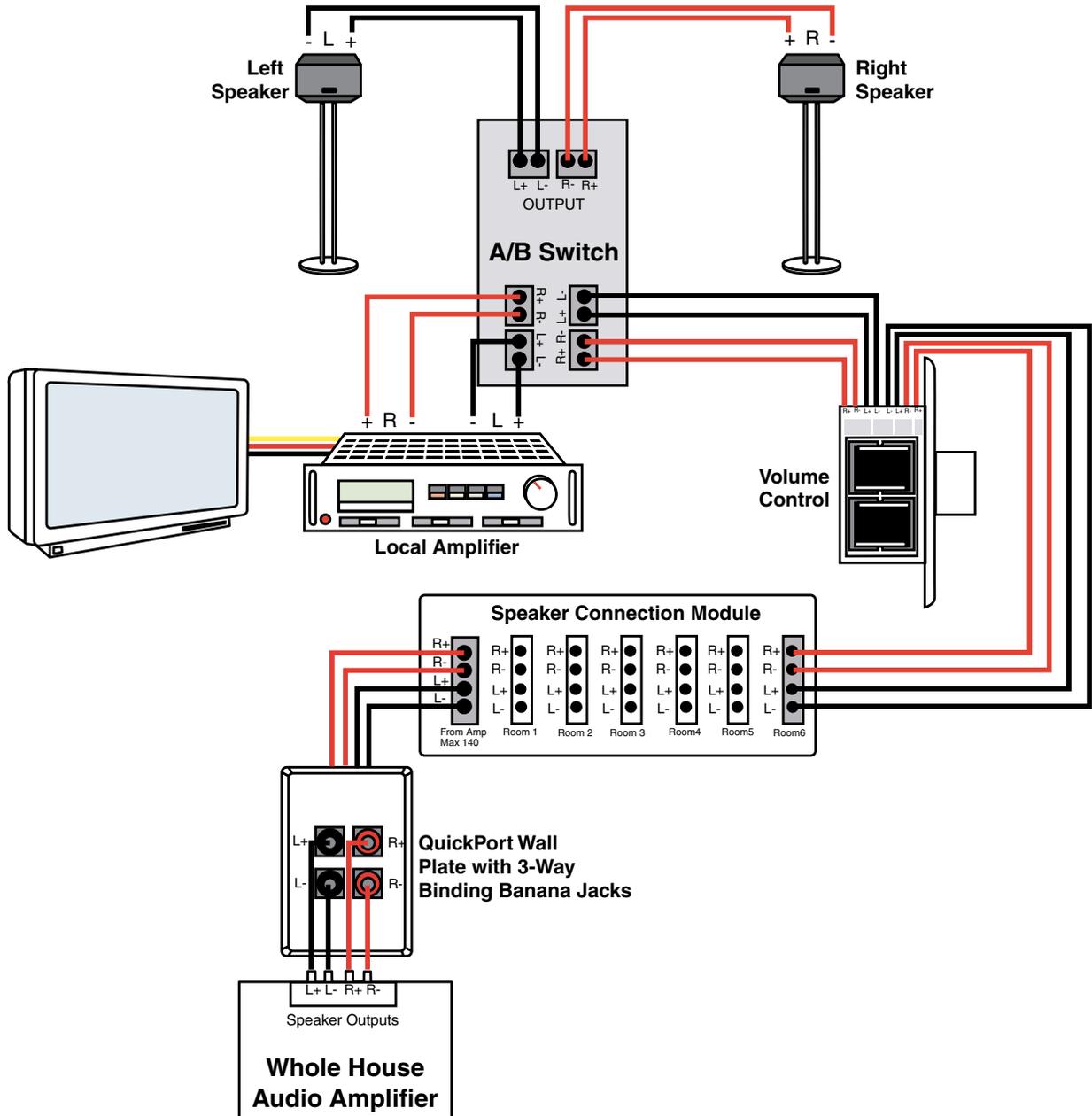
## Figure 2: A/B Switch Wiring



..... Four conductors of speaker wire and 1 CAT 5/5e

-.-.-. Two conductors of Speaker wire and 1 CAT 5/5e

# Figure 3: A/B Switch Application



# Appendix

## Leviton Recommendation for In-Wall Rated Speaker Cables

When speaker cable is installed inside walls, it is important to use cable that is rated for in-Wall use without conduit. This is often referred to as "premise wiring rated". Most speaker cables sold for consumer use are not rated for premise wiring use. There are three strong reasons for insisting on premise rated wiring: First, it complies with the U.S. and Canadian National Electric Codes. Second, it assures that both the materials and the design of the cable meet well-established standards for fire safety ( UL Type CL3 and CSA FAS-90-FT-4 ). And third, the overall design and construction of the cable should eliminate the possibility of physical deterioration or performance degradation after installation.

### Gauge Selection

The impedance of speakers is quite low (usually 4 or 8 Ohms) and the resistance of the cable connecting the speakers to an amplifier becomes quite relevant in determining how much power actually reaches the speaker. For example, a one hundred foot run of 16 AWG cable experiences a round trip resistance of 0.8 ohms. When connected to a 4 Ohm speaker, approximately 17% of the power will be lost to the cable and only 83% will reach the speaker. Larger AWG wire can reduce this power loss. Usually, the speaker wire sizes that are used for whole-house, audio speaker wiring are typically 16 AWG or 14 AWG. Both sizes provide a good compromise between line loss, cost, and ease of installation. And fortunately, most of the equipment available for whole-house, audio systems have connection devices designed for these wire sizes. The use of a non-standard wire size definitely increases the difficulty of installation.

## Power Loss Budget Table

The following Power Loss Budget Table provides a guideline for selecting the right size speaker wire.

**Speaker Wire Power Loss Budget Table**

Speaker Ohms	Db Loss	Power Loss	16 AWG Run (ft.)	14 AWG Run (ft.)
4	0.5	11%	60	100
4	1	21%	130	210
4	2	37%	290	460
4	3	50%	500	790
8	0.5	11%	120	190
8	1	21%	260	410
8	2	37%	580	930
8	3	50%	990	1580

*How to Use this Table: Select Speaker Impedance and Maximum Acceptable Loss, then look up maximum cable run distance.*

A 3dB loss may seem like a lot. But since the ear has tremendous dynamic range, an average person probably won't notice that size loss. And, with the power of most of today's amplifiers, it is quite easy to overcome a 3db loss. However, some high-end amplifiers have special speaker compensation circuits. Over the full range of frequencies handled by a speaker, a high-end unit will perform better at some frequencies than others. Some high-end units sense the response characteristics of the speaker and automatically compensate for non-linear responses (often referred to as servo-ing).

When the resistance of a speaker wire is a significant part of the overall speaker impedance seen by the amplifier, it can have an impact the amplifier's effective compensation capabilities. However, for most amplifiers intended for whole-house use, this is rarely relevant.

# Speaker Cable Comparisons

The types of speaker cables that are most often recommended for In-Wall use without conduit are Monster Cable's Standard Performance, UL CL3 Speaker Cable and two, relatively new, Belden speaker cables from their Brilliance® and New Generation® series. There are three additional manufacturers of premium audio cables who also provide highly regarded types of speaker cable for In-Wall use without conduit. They are: Audioquest; Liberty Wire & Cable; and, WireWorld. Please note that West Penn Wire/CDT manufactures a Communication & Control Cable product (its Catalog No. 226) that is "form-fit-functionally" equivalent to Belden's New Generation® series. (14 AWG consists of 105 strands). Easy to strip and install. Quite flexible. White (CL-500) and Light Green (CL-EZ) outer jackets. Monster Cable is a highly respected manufacturer of premium audio cables.

Manufacturer	Type	Characteristics
<b>Monster Cable</b>	<b>Standard™ Performance</b> S14-2R CL-500 (14 AWG, 2-Conductor, 500 Foot Reel) MSRP = \$ .42 per Foot (Quantity Purchases of 500+ Feet)	Rated UL Type CL3 and CSA FAS-90-FT-4 for premise wiring. Very fine strands (14 AWG consists of 105 strands). Easy to strip and install. Quite flexible. White (CL-500) and Light Green (CL-EZ) outer jackets. Monster Cable is a highly respected manufacturer of premium audio cables.
	<b>Standard™ Performance</b> S14-2R CL-EZ (14AWG, 2-Conductor, 500 Foot EZ-Pull Box) MSRP = \$ .42 per Foot (Quantity Purchases of 500+ Feet)	
<b>Belden</b>	<b>New Generation®</b> 5100UE (14 AWG, 2-Conductor) MSRP = \$ .25 per Foot (MOQ Purchase of 1-K Foot Reel)	Rated UL Type CL3 and CSA FAS-90-FT-4 for premise wiring. Standard and Finer strands (5100UE 14 AWG consists of 19 strands and 8473 14 AWG consists of 42 strands.) Easy to strip and install. Easier to connect to terminals than Monster Cable because of larger strands. Grey outer jackets. New Generation (5100UE) and Brilliance (8473) Speaker Cables by Belden are relatively new in the market. Belden is a highly respected manufacturer of general use and speciality wire/cable.
	<b>Brilliance®</b> 8473 (14 AWG, 2-Conductor) MSRP = \$ .39 per Foot (Quantity Purchases of 500+ Feet)	
<b>Audioquest</b>	<b>SR 15/2</b> SR15/2 (15 AWG, 2-Conductor) MSRP = \$ .35 per Foot (Quantity Purchases of 500+ Feet)	Rated UL Type CL3 and CSA FAS-90-FT-4 for premise wiring. Standard strands (15 AWG consists of 19 strands). Easy to strip and install. Easier to connect to terminals than Monster Cable because of larger strands. Dark blue outer jackets. Audioquest is a highly respected manufacturer of premium audio cables.
<b>Liberty Wire &amp; Cable</b>	<b>UltraCap®</b> 14-1P-UC-WHT (14 AWG, 2-Conductor) MSRP = \$ .39 per Foot (Quantity Purchases of 500+ Feet)	Rated UL Type CL3 and CSA FAS-90-FT-4 for premise wiring. Standard strands (14 AWG consists of 168 strands). Easy to strip and install. Quite flexible. Dark blue outer jackets. Liberty is a highly respected manufacturer of premium audio cables.
<b>West Penn Wire/CDT</b>	<b>Communication &amp; Control Cable</b> 226 (14 AWG, 2-Conductor) MSRP = \$ .25 per Foot (MOQ Purchase of 1-K Foot Reel)	Rated UL Type CL3 and CSA FAS-90-FT-4 for premise wiring. Standard strand (14 AWG consists of 19 strands.) Easy to strip and install. Easier to connect to terminals than Monster Cable because of larger strands. Gray outer jackets. West Penn/CDT is a highly respected manufacturer of general use and speciality wire/cable.
<b>Liberty Wire &amp; Cable</b>	<b>UltraCap®</b> 14-1P-UC-WHT (14 AWG, 2-Conductor) MSRP = \$ .39 per Foot (Quantity Purchases of 500+ Feet)	Rated UL Type CL3 and CSA FAS-90-FT-4 for premise wiring. Standard strands (14 AWG consists of 168 strands). Easy to strip and install. Quite flexible. Dark blue outer jackets. Liberty is a highly respected manufacturer of premium audio cables.
<b>WireWorld</b>	<b>Luna III+®</b> LUSM (15-AWG, 2-Conductor) (LUSM-150 500 Foot Reel) (LUSM-300 1-K Foot Reel) MSRP = \$ .79 per Foot (Quantity Purchases of 500+ Feet)	Rated UL Type CL3 and CSA FAS-90-FT-4 for premise wiring. Standard strands (15 AWG consists of 48 strands). Easy to strip and install. Easier to connect to terminals than Monster Cable because of larger strands. White outer jacket. WireWorld is a highly respected manufacturer of premium audio cables.

# Leviton Recommendation

## RE: Cabling of In-Ceiling and In-Wall Speakers

Based on technical follow-up with Application and Product Engineering personnel at several, major Speaker Manufacturers (BIC-America, JBL, Niles Audio, Polk Audio and SpeakerCraft), Leviton **STRONGLY RECOMMENDS THE USE** of UL Type CL3 / CSA FAS-90-FT-4 rated, 2 Conductor, 14 AWG Speaker Cable in Run Lengths which only create a 1/2 dB Impedance Loss for optimum compatibility with both 4 and 8 Ohm Speaker systems. (Without a comparative reference and with only a 1/2 dB insertion loss in the cable run, the vast majority of Homeowners will not be able to detect a discernable difference in the performance of their speakers. And, the accompanying use of UL Type CL3 / CSA FAS-90-FT-4 Speaker Cable greatly minimizes the likelihood of its behind-the-wall, physical deterioration or performance degradation after initial installation.) However, Leviton **ACKNOWLEDGES** that the **OCCASIONAL USE** of Run Lengths which create a **MAXIMUM** of 1 dB Impedance Loss are **ACCEPTABLE**.

Appendix, Rev-2  
E. C. Hartland, Jr.  
July 3, 2001