

25V, 70V, & 100V Constant Voltage Speaker Systems

by: Joe Ging, E.E.

“Constant Voltage Speaker Systems” have been a source of confusion for people for a long time. It’s ironic that a system that was specifically designed to make life simpler for designers and installers, still causes so much confusion. In this paper we’ll discuss why the constant voltage system was created, the advantages of the system, and some basic system design rule-of-thumb guidelines. Once the mystery behind “Constant Voltage Speaker Systems” has been unlocked, you will probably become a big fan and be able to deal with these systems quite easily. Understanding the limitations of standard 8 ohm systems (also called “low impedance systems” or “voice coil systems” since no matching transformers are used), is an important step toward appreciating the simplicity of “Constant Voltage Speaker Systems”.

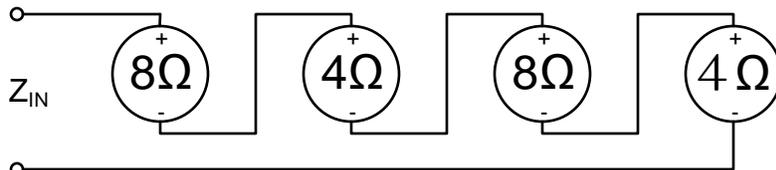
8 Ohm Series/Parallel Speaker System Wiring

The Golden Rule: For any amplifier, it’s important that the impedance of the speaker load always be equal to or greater than the rated output impedance of the amplifier. For example, it is safe for the amplifier if the 8Ω output is used to drive an 8Ω speaker load or a 16Ω speaker load, and it is safe for the 4Ω output of an amplifier to drive a 4Ω load, 8Ω load, or 16Ω load. As long as the speaker load impedance is greater than the rated output impedance of the amplifier, the amplifier is safe. It is not safe for the 8Ω output of an amplifier to drive a 4Ω load and it is not safe for the 4Ω output of an amplifier to drive a 2Ω load. Overloading the output of the amplifier can blow a fuse, trip a circuit breaker, cause audible distortion, and also can damage the amplifier. Ohms Law can be used to determine the impedance of a speaker load using the formulas below.

Note: “Z” is the formula symbol for impedance.

Speakers in Series:

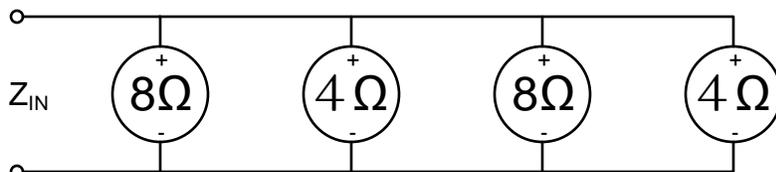
$$Z_{IN} = Z_1 + Z_2 + Z_3 \dots$$



Example: $Z_{IN} = 8 + 4 + 8 + 4 = \mathbf{24 \text{ Ohm Load}}$

Speakers in Parallel:

$$\frac{1}{Z_{IN}} = \frac{1}{Z_1} + \frac{1}{Z_2} + \frac{1}{Z_3} \dots$$

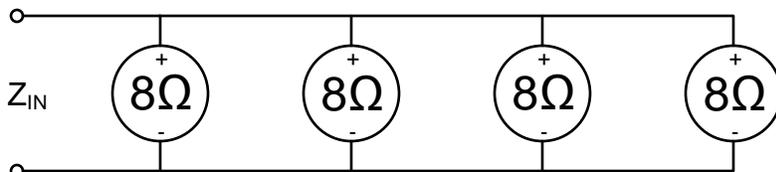


Example: $\frac{1}{Z_{IN}} = \frac{1}{8} + \frac{1}{4} + \frac{1}{8} + \frac{1}{4}$ $Z_{IN} = \mathbf{1.333 \text{ Ohm Load}}$

Identical Impedance Speakers in Parallel:

$$Z_{IN} = \frac{Z}{N}$$

Where Z = Impedance of One Speaker
and N = Number of Speakers In Parallel



Example: $Z_{IN} = \frac{8\Omega}{4 \text{ Speakers}} = \mathbf{2 \text{ Ohm Load}}$

Lowell Manufacturing Company • 100 Integram Drive • Pacific, Missouri 63069 U.S.A.

Call: 800-325-9660

Fax: 636-257-6606

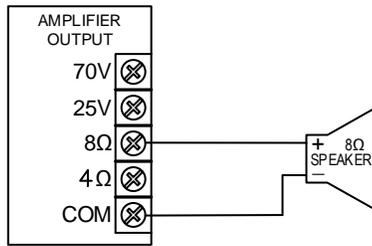
Click: www.lowellmfg.com

Sheet: GSC
REV: 7-19-17

8 Ohm Series/Parallel Speaker System Wiring Examples (Note that polarity is important.)

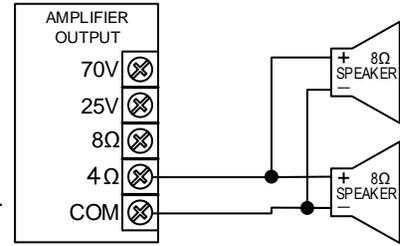
One 8Ω Speaker

Result:
One speaker
receives the
total amplifier power.



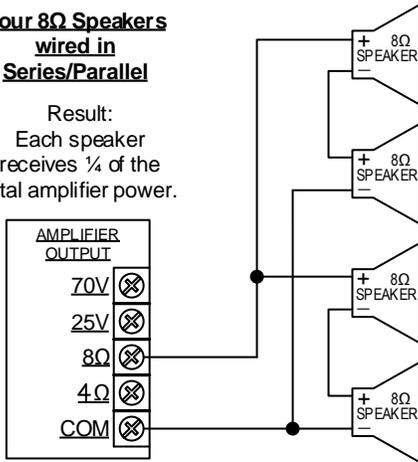
Two 8Ω Speakers wired in Parallel

Result:
Each speaker
receives ½ of the
total amplifier power.



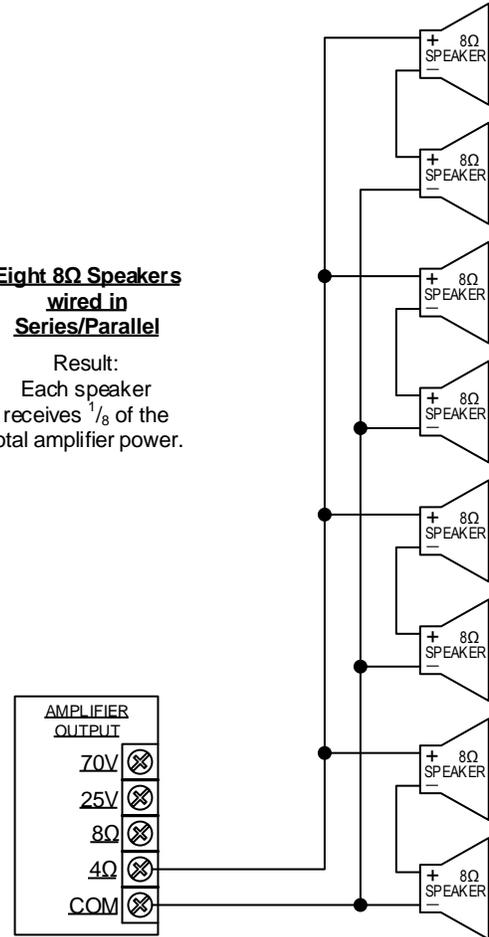
Four 8Ω Speakers wired in Series/Parallel

Result:
Each speaker
receives ¼ of the
total amplifier power.



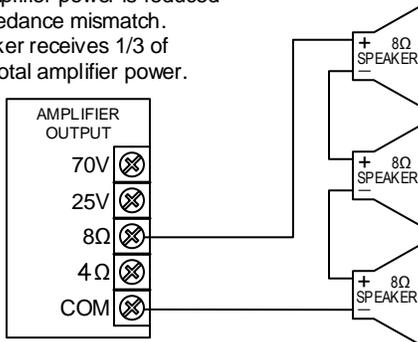
Eight 8Ω Speakers wired in Series/Parallel

Result:
Each speaker
receives 1/8 of the
total amplifier power.



Three 8Ω Speakers wired in Series

Result: Total amplifier power is reduced
due to impedance mismatch.
Each speaker receives 1/3 of
the reduced total amplifier power.



It's important to understand that the maximum transfer of power from the amplifier to the speakers happens when the speaker load impedance exactly equals the amplifier output impedance. For example, if an 8Ω amplifier feeds an 8Ω speaker, the total available output from the amplifier will be delivered to the speaker. If, however, the amplifier with an 8Ω output feeds a 16Ω speaker, not all of the amplifiers available power can be drawn by the 16Ω speaker because of the impedance mismatch. Combinations of series and parallel speakers should be combined to match the amplifier output impedance as closely as possible. Take for example where four 8Ω speakers are to be fed by an amplifier with an 8Ω output. You can't wire those speakers in parallel because that would result in a 2Ω load which is too low for the amplifier. If, however, you wire 2 pairs of speakers in series (so each pair would have an impedance of 16Ω) and then wired those two series pairs in parallel, the resulting speaker load would be 8Ω and that would be a perfect match for the 8Ω output of the amplifier.

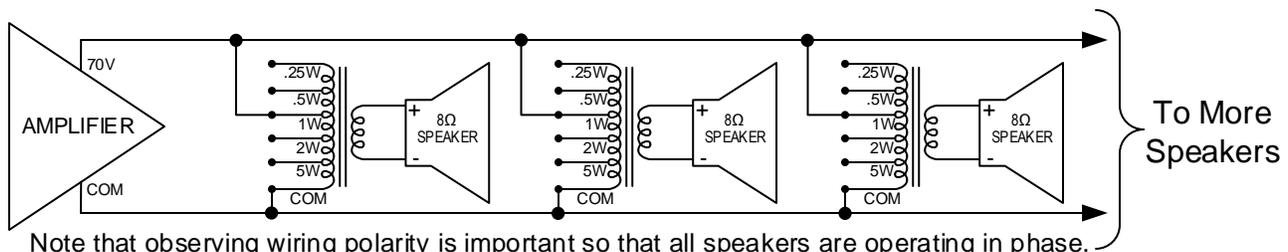
Multiples of 4 speakers can usually be wired in series/parallel to result in a desirable load impedance, but not all speaker systems in the real world have multiples of 4 speakers. For example, what if you had five speakers? There's no way possible to wire five speakers in series/parallel so that all speakers would receive the same power and the impedance would match the amplifier output impedance. What if you have 37 speakers? Same problem. What if you had an office complex with 537 speakers. There is no practical way to wire those speakers in series/parallel to properly load the amplifier and make sure that all speakers receive the same power. There are many technical disadvantages to wiring speaker systems in series/parallel, but the main disadvantage is the complexity of the wiring scheme required when you are faced with a system with many speakers, or an odd numbers of speakers. This is one of the main reasons why "CONSTANT VOLTAGE SPEAKER SYSTEMS" were created.

Constant Voltage System Wiring

It's obvious from the examples just discussed that the ideal speaker system would be designed so that all speakers can be wired in parallel, no matter how many speakers are included in the system. Constant voltage systems use small inexpensive matching transformers (see the Lowell R1810-72 to the right) to artificially boost the impedance of an 8Ω speaker to a much higher impedance. Considering the impedance formulas discussed on page 1, that means that very many speakers can be wired in parallel because the high impedance of the matching transformers results in a load at the output of the amplifier that is still at a reasonable impedance. See the typical 70V speaker system wiring below.



Lowell R1810-72



Note that observing wiring polarity is important so that all speakers are operating in phase.

"Constant Voltage"

Many people get confused by the terminology "Constant Voltage". Some wonder how the output of the amplifier can stay at 70.7V. The answer is, the amplifier output voltage is only at 70.7V when it is at full output. Normally a 70V amplifier is turned down some so the output voltage is less than 70V. The maximum output voltage of a normal 8Ω amplifier is different depending on the power rating of the amplifier. All 70V amplifiers, however, have a 70.7V maximum voltage output level, whether they are 10 watt amplifiers, or 1000 watt amplifiers. That's where the constant voltage term comes from. That is a handy part of the constant voltage system design. If a system has a 100 watt 70V amplifier and more speakers are added so the load is greater than 100 watts, the next larger amplifier (maybe a 70V 150W amplifier) can be used to replace the 100W amplifier. No wiring changes to the speaker circuits are required. No changes to the power taps on the speaker transformers are required. **The key is that the maximum output voltage is 70.7 volts regardless of the power capability of the amplifier.**

25V, 70V, & 100V Systems:

25V, 70V, and 100V constant voltage speaker systems are available. A few clarifications will simplify our discussion as we move forward with this paper. First of all, you may have already noticed that the terms “70V” and “70.7V” have been used interchangeably. The correct voltage level is 70.7V, so for all calculations, 70.7V will be used. 70.7V was chosen by the system designers simply to make the calculations easier. Typing 70.7 is cumbersome, so very often 70V is used as an abbreviation. Keep in mind though, that 70.7V is the actual voltage value used. For the remainder of this paper we will put the discussion of 100V speaker systems on the back burner. Some Lowell speaker systems have ratings for 25V, 70V, and 100V operation. The “100V” settings are included because those speaker products are marketed outside of the United States. In the US, 70.7V is the highest voltage speaker system where Class 2 wiring can be used without conduit. In the United States, if a 100V speaker system is installed in a commercial building, Class 1 speaker wiring must be used and it must be installed in conduit. That makes the sound system installation very expensive, so for all practical purposes, 100V speaker systems are used overseas and are typically not installed in the United States. An exception to that rule could be when high powered speakers are installed with very long speaker lines. As long as the Class 1 wiring and conduit costs can be justified, 100V systems can be installed in the United States, but that does not happen very often. That application is so rare for our target audience in the US, we are going to concentrate mostly on 25V and 70V speaker systems for the remainder of this paper.

Other Constant Voltage System Advantages:

The ease of parallel wiring is not the only advantage of constant voltage speaker systems.

Cable Power Loss:

Any time current flows in a conductor, there is heat loss due to the impedance of the conductors. Ohm’s Law tells us that $P_{LOSS} = I^2 \times Z$ where P_{LOSS} is the power lost in the cable, I is the current in amps in the cable, and Z is the impedance in ohms in that length of cable. Obviously because the current is squared in the formula, any increase in current causes a large increase in heat loss in the cable. That’s why utility companies distribute electrical power from the power plant at a very high voltage. Again according to Ohm’s Law, $P = VI$ where $V =$ voltage and $I =$ current. If the power needed at your home were to be distributed at 110V, the current in the transmission line would have to be very high to get enough power to your home. If instead, the transmission voltage is 500,000V (for example), the current in the transmission line could be very low and still deliver the same amount of power to your home. The transmission voltage is stepped down at a transformer in your neighborhood before it enters your house. For that short distance, the heat loss in the cable is minimal. This same principal is used in a constant voltage speaker system.

Longer Speaker Lines or Smaller Gauge Speaker Lines:

The reduced cable loss that results from higher amplifier voltages in constant voltage speaker systems, allows the designer the option to run speaker lines farther, or to use smaller gauge cable to reduce the cost of the speaker system installation. Smaller gauge cable has a higher impedance so the loss is higher, but that loss is offset by the higher voltage of the amplifier.

Cable Power Loss (Continued):

Example: We wish to deliver 1W of power to a speaker. Assume that the wiring to that speaker has 1Ω of total impedance in the sending and return conductors.

For an 8 ohm speaker, the current would have to be .3536A for $I^2 \times (8\Omega)$ to equal 1 watt.

The question is, how much power is lost in heat in the cable?

$P_{Loss} = I^2 \times Z = (.3536A)^2 \times 1\Omega =$ so .125W would be lost in heat in the wire.

Using the same example for an 25V speaker, the 1 watt tap impedance would be 625Ω.

The current would have to be .04A for $I^2 \times (625\Omega)$ to equal 1 watt.

The question is, how much power is lost in heat in the cable?

$P_{Loss} = I^2 \times Z = (.04A)^2 \times 1\Omega =$ so only .0016W would be lost in heat in the wire.

Using the same example for an 70.7V speaker, the 1 watt tap impedance would be 5000Ω.

The current would have to be .01414A for $I^2 \times (5000\Omega)$ to equal 1 watt.

The question is, how much power is lost in heat in the cable?

$P_{Loss} = I^2 \times Z = (.01414A)^2 \times 1\Omega =$ so only .0002W would be lost in heat in the wire.

The examples above clearly demonstrate that the higher the voltage of the constant voltage speaker system, the less heat loss there is in the cable.

Why choose 25V, 70V, or 100V Voltage System:

100V constant voltage systems have the least amount of loss in the speaker wires, but as we discussed on page 4, code restrictions requiring Class 1 wiring and conduit make 100V systems cost prohibitive in the United States. But why then would anybody use a 25V system instead of a 70.7V system when the loss in the cable is 8X greater for a 25V system than for a 70V system? There are two main reasons for the use of 25V systems in the US. In certain areas of the country, code limits speaker systems to 25V for systems in use in public buildings. 25V systems are typically used for hospital nurse call systems and for school intercom systems. Intercom systems often have talk-back features where the talk-back circuitry operates with less noise if the speaker line impedance is in the 600 ohm range. A 1W tap on a 25V speaker has an impedance of 625 ohms. A high impedance microphone cable can't run very far without introducing noise and that's why low impedance microphones are used. The same applies to talkback intercom lines where the speaker is used as a microphone in the talkback mode. For those reasons, 25V constant voltage speaker systems still have their place in the industry, but 70V systems are by far the most popular in the United States.

Adding and Removing Speakers:

Low impedance series/parallel systems have another major drawback. Even if you manage to wire the series/parallel system to result in a reasonable load impedance for the amplifier output, adding or deleting speakers is a major problem. In a series/parallel configuration, adding a speaker changes everything including the load on the amplifier and how much power each speaker receives. Constant voltage systems don't have this problem. As long as adding up the speaker taps on all speakers does not exceed the power rating of the amplifier, speakers can be added or deleted and have no affect on the operation of the other speakers.

When One Speaker Burns Out:

Low impedance series/parallel speaker systems have serial strings that are wired like some Christmas lights where if one bulb burns out, the entire serial string of lights goes out. If one speaker voice coil burns out resulting in an open line in a serial string of speakers, that entire string of speakers will quit working. Again, a constant voltage system does not have this problem because all of the speakers are wired in parallel. If one speaker voice coil burns out resulting in an open line, all of the other parallel speakers will continue to work normally.

Adjusting the Volume of a Single Speaker:

Unless expensive L-pads are used (that present a constant impedance to the source amplifier), any attempt to adjust the volume of one speaker in a series/parallel speaker system will also affect the volume of other speakers fed by that amplifier. Constant voltage speakers systems don't suffer from this drawback. The transformer taps on an individual speaker can be changed to make the volume of that speaker higher or lower, without affecting the volume of the other speakers on that string. Note that constant voltage speaker matching transformers typically come with multiple taps like 1/4W, 1/2W, 1W, 2W, and 5W. If it will provide sufficient sound pressure level, it's good design practice to tap most of the speakers at the center tap (1W in this case). That allows adjustment of that one speaker upward by 2 taps if more volume is required, and downward by 2 taps if less volume is desired. If, for example, all of the speakers were tapped at 5W and there was a need for the volume of one speaker to be increased in relation to the other speakers, the only remedy would be to lower the tap settings for all of the other speakers on the string and turn the amplifier up. It is good design practice to tap speakers in a way that allows adjustment in volume for a single speaker if required.

Adjusting the Volume of a String of Speakers:

To adjust the volume of a string of speakers, an inexpensive wall-mount or rack-mount autoformer volume control can turn the volume of the string of speakers up or down in a constant voltage system. Autoformer volume control adjustments will not change the volume of the rest of the speakers that are tied to the same amplifier and are not fed by that volume control.

Priority Attenuators:

Constant voltage systems can incorporate special priority attenuator autoformer volume controls where a DC voltage can be used to trip a relay at the volume control which switches the volume control to full volume regardless of the setting of the knob. This feature is important for emergency paging systems when it is important that all users can hear the emergency page, even if their volume control is turned down. The priority volume control relay must be triggered by a separate 24VDC power supply that is switched by the page switch of the paging microphone or by some other dry contact closure.

Dual Voltage Speakers:

Because the power drawn by a speaker from a 25V or 70V amplifier is simply determined by the impedance of the speaker's transformer winding, you will find that many speakers offered by Lowell Manufacturing include dual voltage transformers. The Lowell R1810-72 for instance is equipped with the Lowell TLM-572 transformer which has 25V and 70V taps at power tap values of 1/4W, 1/2W, 1W, 2W and 5W. This allows a Lowell customer to only stock one speaker model that can be used on either 25V or 70V speaker systems.



Lowell
R1810-72

Constant Voltage System Calculations

Calculations for constant voltage speaker systems are based on Ohm's Law as shown below:

Ohms Law

V = Voltage Z = Impedance I = Current P = Power

$$V = IZ \quad I = V/Z \quad Z = V/I \quad P = VI \quad P = V^2/Z \quad P = I^2Z$$

Derivation for 70.7V Systems

$$P = V^2/Z = (70.7V)^2/Z = 5000/Z$$

$$Z = 5000/P$$

Derivation for 25V Systems

$$P = V^2/Z = (25V)^2/Z = 625/Z$$

$$Z = 625/P$$

For 70 Volt System	$P = \frac{5000}{Z}$	$Z = \frac{5000}{P}$
For 25 Volt System	$P = \frac{625}{Z}$	$Z = \frac{625}{P}$

Example Calculations

- 1) What is the output impedance of a 100W 70V amplifier? $Z = 5000/P = 5000/100W \quad Z = 50\Omega$
- 2) What is the impedance of a 5W tap on a 70V transformer? $Z = 5000/P = 5000/5W \quad Z = 1000\Omega$
- 3) What is the impedance of a 1W tap on a 25V transformer? $Z = 625/P = 625/1W \quad Z = 625\Omega$
- 4) What is the impedance of a 1W tap on a 70V transformer? $Z = 5000/P = 5000/1W \quad Z = 5000\Omega$
- 5) How much power would a 45Ω speaker draw on a 25V system?
 $P = 625/Z = 625/45\Omega \quad P = 13.89 \text{ watts.}$
- 6) How much power would a 5Ω transformer tap draw on a 70V system?
 $P = 5000/Z = 5000/5\Omega \quad P = 1000 \text{ watts.}$
- 7) How much power would a 25V transformer 1 watt tap draw if connected to a 70V system?
 Calculate the impedance of the tap. $Z = 625/P = 625/1W \quad Z = 625\Omega$
 Calculate how much power that tap would draw on a 70V system.
 $P = 5000/Z = 5000/625\Omega \quad P = 8 \text{ watts.}$
- 8) A common mistake is when a customer adds an 8Ω speaker to a 70V line. Often the speaker burns out, a circuit breaker or fuse is blown at the amplifier, or the amplifier is damaged.
 To understand why that happens, let's calculate how much power an 8Ω speaker would draw on a system that is operating at a full 70.7V. $P = 5000/Z = 5000/8\Omega \quad \mathbf{P = 625 \text{ watts.}}$
 That would typically burn up the speaker and overload the amplifier.

Constant Voltage System Design

The good news is that the formulas on the previous page rarely need to be used for simple system design. The designers of the constant voltage system, set it up so the math and technical knowledge required to design and install a system are minimal. Note that in this paper we will only discuss the electronic "Rules of Thumb" to design a constant voltage system. Other Lowell technical papers are available on the Lowell Manufacturing website (www.lowellmfg.com) that cover speaker placement, coverage patterns, speaker cable, sound pressure level, and other topics. See the links below for those papers:

- 1) Checking Above the Ceiling
http://www.lowellmfg.com/wp-content/uploads/Checking_above_the_ceiling_before_you_cut.pdf
- 2) Distributed System Speaker Spacing
<http://www.lowellmfg.com/wp-content/uploads/LowellDSSS-1.pdf>
- 3) Paging Horn Spacing
<http://www.lowellmfg.com/wp-content/uploads/LowellPHS.pdf>
- 4) Speaker Cable Gauge
<http://www.lowellmfg.com/wp-content/uploads/What-Gauge-Speaker-Cable-Should-I-Use.pdf>
- 5) Speaker Power Requirements
<http://www.lowellmfg.com/wp-content/uploads/LowellDSPR.pdf>
- 6) Sound Masking System Design
<http://www.lowellmfg.com/wp-content/uploads/LowellSMSD.pdf>

Design Rule 1: Speaker Load < or = the Amplifier Power Rating

Add up the transformer taps for all speakers in the constant voltage system, and the sum can never exceed the rated output power of the amplifier. For example, if you plan to tap the speaker transformers at 1W each and you are using a 100W 25V or 70V amplifier, you cannot use more than 100 speakers. $1\text{W}/\text{speaker} \times 100 \text{ speakers} = 100 \text{ watt load}$.

Design Rule 2: Headroom

Even though loading the amplifier to its power rating as described in "Design Rule 1" in theory is acceptable, it is much better design practice to load the amplifier to only about 80% of the amplifier power rating. When headroom is included in the design, the amplifier will run cooler and last longer. There is always a chance that a speaker or two will need to be added to the system to cover dead or forgotten spots. In many cases a speaker or two needs to be switched to a higher power tap setting to make those speakers louder. It's just not good design practice to design a speaker system that is fully loaded with no possible increase in a few taps or expansion with a few speakers as might be needed. The difference in price in different sized power amplifiers these days is minimal. It's often said these days that "Power is cheap". Do yourself and your customers a favor and make it your standard design practice to oversize the amplifiers you use to allow as much headroom as possible.

Design Rule 3: Volume Control Size

When a wall-mounted or rack-mounted autoformer volume control is used to feed a string of speakers, always make sure that the sum of all transformer power taps on the string of speakers, adds up to less than or equal to the power rating of the volume control. Overloading a volume control can result in overheating and premature failure.

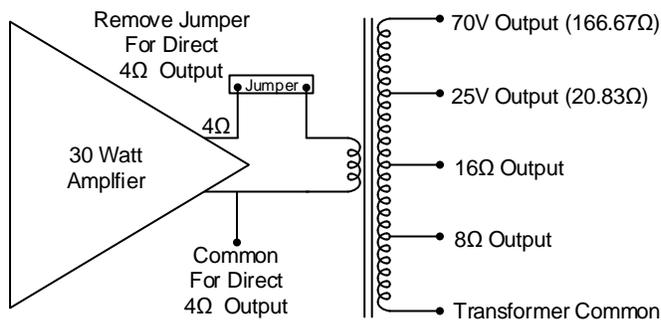
Disadvantages of Constant Voltage Speaker Systems:

There's always a price to pay, isn't there? Using a large gauge cable to minimize heat loss in the wire and using no transformers would result in the best frequency response transfer from the amplifier to a speaker. Those low-cost transformers used in constant voltage systems do introduce some insertion loss and can affect the frequency response of the system. That's the cost of the huge advantage of being able to use smaller cable with less loss and being able to wire all speakers in parallel. For paging, background music, and foreground music systems, that trade-off is usually considered to be well worth it. For the times when a slight loss in frequency response is not acceptable, Lowell Manufacturing offers many higher quality matching transformers including the top-of-the-line TLS Series. The 100 watt Lowell TLS-10070 transformer shown to the right, has been designed to have very low insertion loss with almost no effect on the frequency response of the speaker. A large high quality transformer like the TLS-10070 wouldn't be practical to use for a paging or background music speaker, but for high quality Pro Sound speakers like the Lowell I-Mount Series and IMC Series, high quality transformers allow the use of an easy to wire 70V speaker system without the insertion loss and frequency response degradation that lower cost transformers can introduce. The system designer must determine what compromises are acceptable for a particular design depending on the performance requirements.



Amplifiers for Constant Voltage Speaker Systems:

When constant voltage systems were first invented, the easiest way to boost the output voltage of a typical amplifier was by using what is called an "output transformer". An output transformer is simply a voltage step-up transformer. Typically a voice coil standard amplifier was used that had a 4Ω or 8Ω output. In the case of an 8Ω amplifier, the 8Ω output was available to directly feed an 8Ω speaker. Usually a strap or jumper was provided on the rear of the amplifier so the 8Ω output could be connected to a built-in output step-up transformer. A 25V output and 70V output was available to feed constant voltage speaker lines. As amplifier technology progressed, it became common for 4Ω direct outputs to be available which could feed a pair of 8Ω speakers that were wired in parallel. When the 4Ω amplifier output was connected to the 4Ω primary of the output transformer (usually by a jumper or switch on the amplifier), secondary taps for 8Ω, 16Ω, 25V, and 70.7V outputs were then typically available. In recent years, modern amplifier designs have made it possible to drive 25V or 70V outputs directly without the need for an output transformer. Often high end amplifiers now have a switch to switch the output from an 8Ω output to a 70.7V output so the same amplifier could be used for either purpose. In fact, many 2-channel amplifiers now have the option of setting one output channel for 8Ω operation, and the second channel for 70V operation. See the typical 30W amplifier output and output transformer shown below:

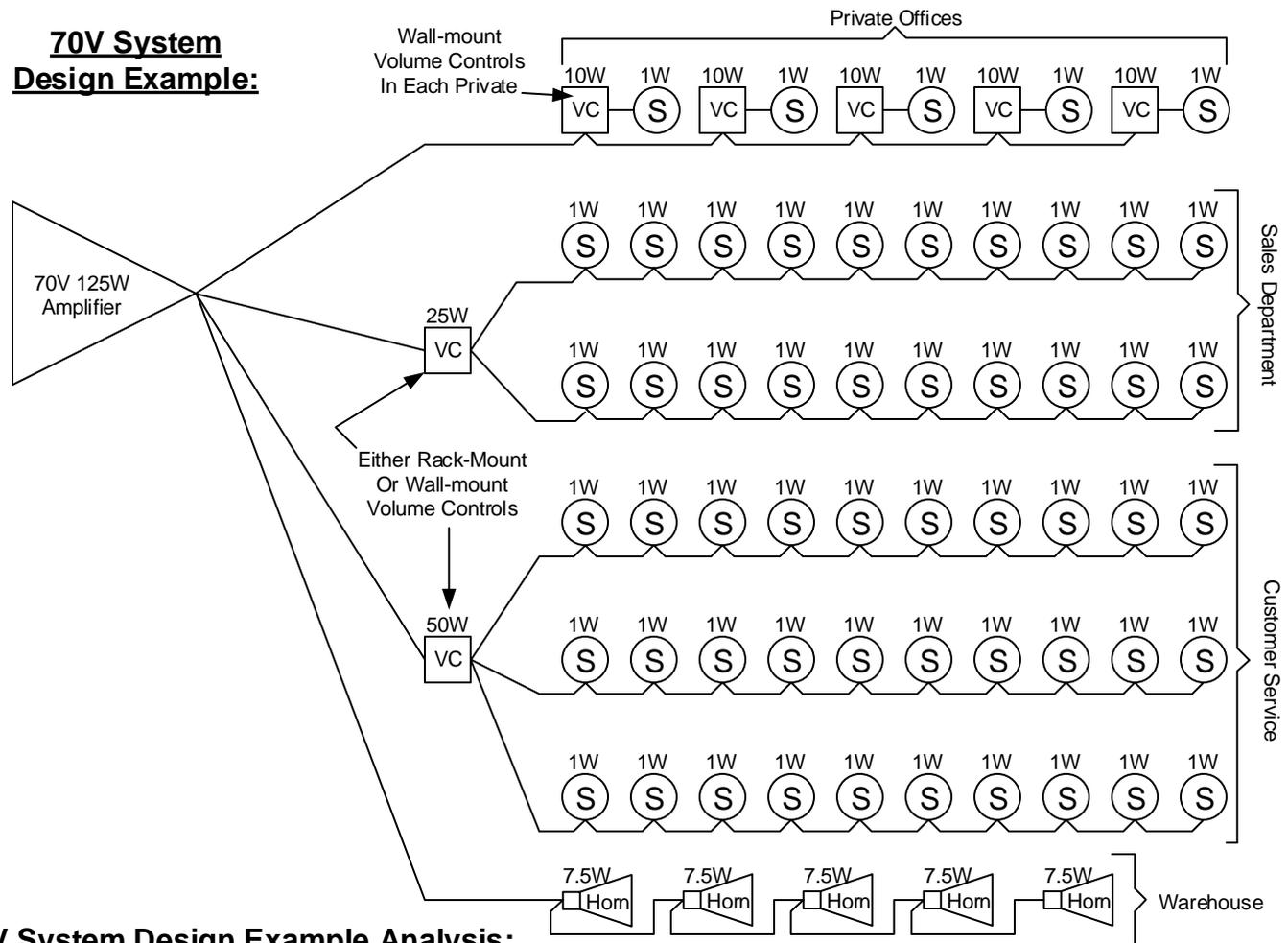


Notice how the impedance of the 25V and 70V outputs can be calculated using the formulas introduced on page 7.

$$Z_{25} = 625/P = 625/30W = 20.83\Omega$$

$$Z_{70} = 5000/P = 5000/30W = 166.67\Omega$$

**70V System
Design Example:**



70V System Design Example Analysis:

The example above assumes that the designer has determined the proper speaker spacing for the application and has determined that the tap settings shown are sufficient to provide the sound pressure level required. First, let's confirm the size of the amplifier. A 125W amplifier loaded at 80% to provide 20% of headroom, will power a usable speaker load of no more than 100W. The sum of all speaker taps shown is $(7.5W \times 5) + (1W \times 55) = 92.5W$ load. That is less than the 100W value at 80% of the amplifier's capability so the amplifier size is appropriate.

Each private office has a ceiling speaker tapped at 1W with a 10W wall-mounted volume control so that is certainly acceptable. The feed daisy chains between the volume controls and then each volume control feeds the local speaker.

The Sales Department has a total speaker load of 20W. The 25W wall-mount volume control is a good choice. The 2 strings of speakers would not have to home run to the volume control. All 20 speakers could daisy chain and then be fed by the volume control. There is probably some practical layout reason why this makes sense to the designer.

The Customer Service Department has a total speaker load of 30W. The 50W wall-mount volume control is a good choice. The 3 strings of speakers would not have to home run to the volume control. All 30 speakers could daisy chain and then be fed by the volume control. Again, there could be some practical layout reason why this makes sense to the designer.

It would be unusual for a volume control to be located out in the warehouse. This system would be balanced by setting the level at the amplifier for the warehouse horns, and the wall-mount volume controls would be set for the desired sound pressure level in the other areas.