Commercial Audio

REMOVING THE MYSTERY FROM CONSTANT VOLTAGE DISTRIBUTION SYSTEMS

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Removing the mystery from Constant Voltage distribution systems

We have all experienced constant-voltage (CV), distributed-loudspeaker, sound systems in restaurants, airports, hotels and churches. If you are confused about how these systems work, you are likely in the majority. The theory and workings of CV sound systems, which are most commonly 70V systems in the USA, are often misunderstood. Whether it is a 70V (70.7V), 100V, 25V or other system, the first vision that often comes to mind is a medium quality paging or background music system. In reality, CV systems can be of high quality and can solve problems not easily solved in other ways. If you are willing to wade through a bit of technical explanation, I think you will find these systems pretty easy to understand. The analysis will include a few simplifications but they will not materially affect our conclusions.

To better explain these systems, we will start with an explanation of why they are used. CV systems are generally used for one or more of the following reasons:
- Many speakers need to be connected to a single power amplifier.
- Some of the speakers need to be at a different volume.
- Some of the speakers need to be turned on or off.

We will also examine whether this approach can be used to reduce losses when driving a loudspeaker a significant distance from the amplifier.

So why are the above situations difficult using a conventional low impedance speaker approach? Let's start by trying to connect 5 identical, 8 Ohms speakers to an amplifier with a 4 Ohm output. (figure 1) If we wire the 5 speakers in parallel, the combined impedance is 8/5 = 1.6 Ohms which is too low for the amplifier. If we connect them in a parallel-series combination (two speakers in parallel in series with 3 speakers in parallel as shown in figure 2) the impedance works, but the power would not be evenly divided between speakers and the amplifier is not able to deliver its rated power.
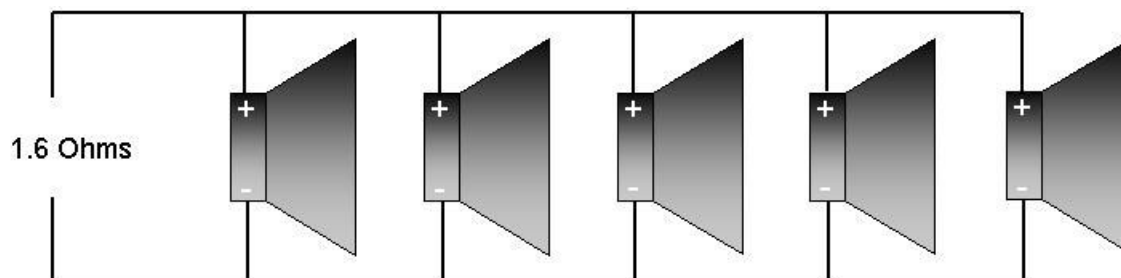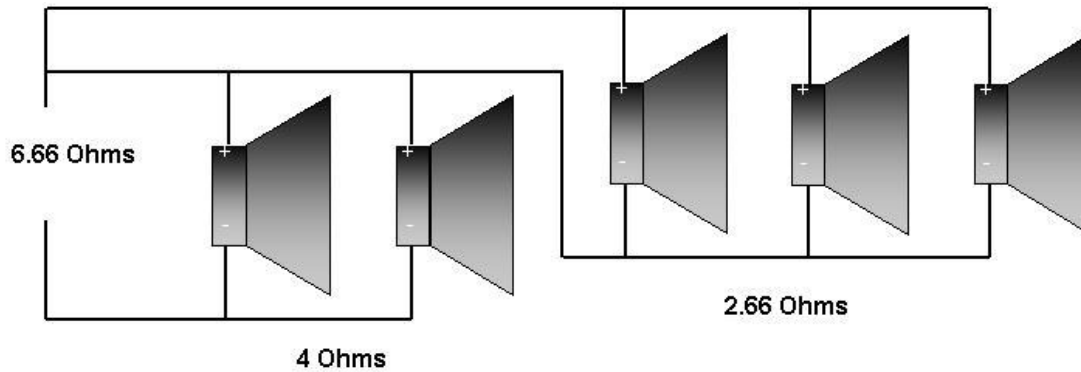

1.6 Ohms

Figure 1

Figure 2

If we start mixing different speakers or requiring different volumes from different speakers, the wiring starts to boggle the mind.

If we use a parallel-series arrangement and now want to turn off a speaker, an equivalent load resistor must be switched in place of the speaker to keep the volume from changing in the remaining speakers.

Now let's look at what happens when we have a loudspeaker located 200 feet from the amplifier. For this example we will use 200 feet of 18-gauge wire to connect an 8-Ohm speaker to an amplifier that produces 100-Watts into an 8-Ohm load (figure 3). The resistance of the wire is 2.6 Ohms. Because of the load resistance the amplifier sees increases to 10.6 Ohms, much of power is lost in the wire, the speaker will only receive 57 Watts! This amounts to a 2.4 dB loss in signal. Can the use of CV technology improve this situation or are there better approaches?   Stay tuned.
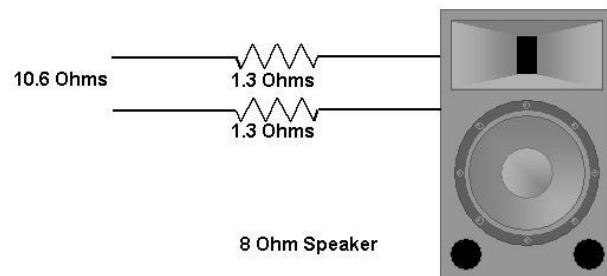

Figure 3

So now that we have looked at some applications where conventional systems are difficult to use or have limitations, let's examine how a constant voltage system performs in these same situations. But first let's get a handle on what a CV system is and how it works.

The most common example of a constant-voltage distribution system is the AC power system in your home or business. When you plug in a lamp or appliance, you are probably not thinking of the how the impedance of the load relates to the minimum load impedance of the circuit.   In the United States, you only need to check to be sure that line voltage matches the requirements of the device (120VAC typical) and the combined power drawn from the circuit is below its maximum rating (typically 2400 Watts) for a 20 Amp circuit.

A constant voltage system works the same way. Each speaker has a matching transformer with an input voltage (e.g. 70V) and Wattage rating. As long as the voltage rating of the transformers and amplifiers are the same (70 V in this example) and the Wattage taps of all of the loads (speakers and transformers) add up to less than or equal to the amplifier power rating, you are all set.

When the situation requires that the volume be different for some speakers, a higher or lower transformer Wattage tap can be selected in those locations.   Each doubling or halving of transformer power tap, produces a 3-dB change is sound level. 4 times the power yields 6 dB more SPL from the speaker.

Now let's look closer at how a CV system works.   If we install a 70V CV system, does that mean that the speaker line always measures 70 Volts?   NO! Although these systems are similar in many ways to our AC power system (ease of connecting multiple loads and lower power loss), the power being distributed is very different. In the USA, our AC power system has a voltage and frequency that is (pretty much) a constant (120VAC, 60Hz). In our audio CV distribution system the voltage and frequency of the signal vary to represent the audio being distributed. So if the voltage of our constant voltage distribution system is not constant, why is it called a constant-voltage distribution system? The "constant" in our constant voltage audio system is that **ALL** CV power amplifiers have a specified AC output voltage (70V in our example) **WHEN** they deliver their rated output power with a sine wave input.

This "constant" output voltage specification allows transformers to be designed that can be used on any system of that voltage with predictable results. In practical terms, the CV system provides a standardized way of connecting many speakers to an amplifier so that the combined load impedance is correct. Instead of computing parallel and series impedance combinations, the installer simply adds the Wattage tap of the transformers to make sure it does not exceed the power amplifier rating.

To design and install a CV system with multiple loud speakers:
- Parallel all of the speaker transformers being careful to make sure that we keep the polarity the same on all speakers. All of the common terminals of the transformers connect to one terminal of the amplifier and the Wattage tap of all to the other.
- Set the Wattage taps as necessary to get the appropriate level in each location. Each doubling or halving of power to a speaker results in a 3 dB change on sound level.
- Make sure that the total Wattage does not exceed the rating of the amplifier. It is a good idea to leave a little headroom in case taps need to be changed. 10% is a good target.

Examination of Losses driving one or two speakers in a remote location

Now that we have explored the advantage of constant voltage systems for creating distributed loudspeaker systems, let's take a more in depth look at situations where we want to deliver power to one or two remote loudspeaker(s).   We will look at the factors in choosing either a CV or low-impedance drive system. We will also look at selecting an amplifier and explore the impact of wire gauge choice.
NOTE: Details of the math used to make loss calculations are detailed at the end of the paper.

Is CV or Lo-Z direct a better approach?
Before we jump into a detailed comparison of designs using these two approaches, let's look a little more at some of similarities and differences.

Over the years, amplifiers have become more efficient and produce higher power. The use of Constant Voltage amplifiers for driving a single loudspeaker at distant location has decreased as the power levels have increased. To get a better feeling this, let's begin by looking at the load impedance on 70 Volt and 100 Volt speaker lines as a function of power.

Load impedance as a function of power on CV systems.

	50 W	100W	200W	300W	400W	500W	600W	700W
70.7V	100Ω	50Ω	25Ω	16.7Ω	12.5Ω	10Ω	8.3Ω	7.1Ω
100V	200Ω	100Ω	50Ω	33.3Ω	25Ω	20Ω	16.7Ω	14.3Ω

	800W	900W	1000W	1100W	1200W	1300W	1400W	1500W
70.7V	6.2Ω	5.6Ω	5Ω	4.5Ω	4.2Ω	3.8Ω	3.6Ω	3.3Ω
100V	12.5Ω	11.1Ω	10Ω	9.1Ω	8.4Ω	7.7Ω	7.1Ω	6.6Ω

Table 1

Looking at the tables above, we discover that if we want to deliver 600 Watts to an 8 Ohm loudspeaker on a 70 Volt line, the load is 8.3 Ohms. This is virtually the same as driving the loudspeaker directly. Using a 70 V line to drive this speaker would only add cost and additional power losses as you will soon see.

As you can see from the above table, as the power levels get higher, the impedances drop to values that are typical of low-impedance, direct-drive systems. For 70V systems, the advantage of reduced wire loss disappears quickly as the power levels go up. Using a 100V system can help at intermediate power levels, but there are additional code requirements for running those lines that must be observed.

Lo-Z (2, 4 or 8 Ohms)
In a Lo-Z direct system the one or two 8 Ohm speakers are directly connected to the amplifier. The losses in this system are primarily due to the loss in the wire between the speaker and amplifier.
CV
Power companies distribute its power over distances at high voltages, which is then transformed to the lower voltages we use in our homes and businesses. Depending on the power level, CV systems use this same approach by starting with a higher voltage at the power amplifier which is then stepped down at the speaker.

There are two loss terms we need to consider. We still have loss in the wire, although it may be less, but we also have a loss in the transformer that steps the voltage down to the loudspeaker.

Let's take a second look at our earlier example system with an 8-Ohm speaker connected to a 100-Watt amplifier using 200 feet of 18-gauge wire. We can determine the loss for this example

by using table 2. The loss for the Lo-Z approach was 2.44 dB and speaker only received 57 Watts.

Now let's look at the same situation but with a 70V system. Determining the wire loss is a little more complicated. We will need to determine resistance of the load and the resistance of the wire. Using Table 1 to get the resistance of the load (50 Ohms) and multiplying the resistance per foot of #18 wire (from Table 2) by 200 feet we get (2.6 Ohms). We can then use these numbers to determine that our wire loss is only .44 dB. If we assume that the loss in the transformer is .4 dB we have a total loss of .84 dB and we deliver 82 Watts to our loudspeaker. This is an improvement over the first approach.
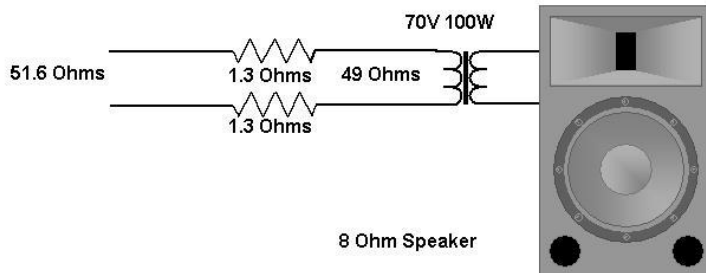

Figure 4

Now let's look at what gauge wire would be required to achieve this same performance using the Lo-Z approach. Looking at the 8 Ohm wire loss chart for 200 feet, 0.84 dB loss falls between 12 and 14 gauge wire. We can use this information to determine the appropriate solution.

Example 2

Let's now look at a specific example of an Elements 115C, 8 Ohm speaker mounted on a light pole at a high school football field. The amplifier is installed in the press box which requires 200 feet of cable.
First let's examine the CV 70 Volt solution. We can install an AutoMatch II, 70V transformer at the loudspeaker and tap it at 400 Watts. We will use 12 gauge wire from the amplifier to the loudspeakers. For now, we will assume that the amplifier can deliver the required power.
Now let's look at the losses. From the chart we have a wire loss of 0.44 dB and a loss of 0.4 dB in the transformer which results in loss of 0.84 dB and we deliver 335 Watts to the loudspeaker.

For the Lo-Z approach, we can use the 8 Ohm wire loss chart (Table 2) for 200 feet we find that we lose 0.68 dB, delivering 342 Watts into the loudspeaker. (400W * 10^(0.68/10)=342 Watts)

Conclusion:
As you can see the losses are virtually identical. Directly driving the 8 Ohm speaker costs less, has fewer components and allows the speaker to be driven to more than 400 Watts if desired.

Example 3

Let's use the same situation as example 2 but place two 8 Ohm speakers at the end of the speaker line. In the CV 70 Volt solution, each loudspeaker will have its own transformer.
In this case the CV 70 Volt system has a loss of 1.25 dB delivering 328 Watts to each speaker. With the Lo-Z system, we have a loss of 1.3 dB and we deliver 296 Watts to each speaker. Wire gauge also factors into these applications.

Conclusion:
Same as example 2
As we have confirmed with the above examples, as we start delivering more power to speakers in a remote location, the advantage of using a 70V line disappears.

Comparing CV and Lo-Z solutions

We have shown that for applications with numerous loudspeakers, CV systems provide an excellent solution. When we look at applications where we have few loudspeakers at distance from the amplifier, the CV solution loses its advantage in many cases. Comparing the approaches, the cost of CV systems is often higher due to increase cost of the amplifiers and the cost of transformers. The use of transformers generally limits the low frequency response to 50 Hz or so.

Now we need to select an amplifier

Choosing the appropriate amplifier depends or at least is affected by several factors:
- The total wattage of the load
- The number of loudspeakers that make up the load
- The distance from the amplifier to the furthest loudspeaker
- Is there more than one loudspeaker zone?

For CV systems the Commercial Audio division of Peavey Electronics has numerous solutions from a 50 Watt single channel unit with mic/line input, 300 Watt single channel amplifiers with mixer and high power multichannel amplifiers. Some of these have remote control capabilities and digital audio inputs.
For some applications, conventional Lo-Z amplifiers can directly drive a 70 or 100 Volt line. For lower power applications, a conventional amplifier matched to the Automatch II transformer can provide 70V or 100 V Outputs.

Examples
Pro-Lite 2.0
4 Ohm 530 Watts per channel, 46 V
8 Ohm 300 Watts per channel, 49 V
8 Ohm 1060 Watts Bridged, 92 V to 98V depending on load.
With this amplifier wired in Bridge mode, it can drive a 100V line up to 1060 Watts.
Up to 530 Watts, the Wattage taps are pretty accurate. As you approach 1000 Watts, the output voltage drops some and actual output at each tap is about 85% of the rated output which is about a 0.72 dB lower than the maximum level. So from a practical standpoint, the drop in output is not noticeable.

Pro-Lite 3.0
4 Ohm 830 Watts per channel, 57.6 V level
8 Ohm 450 Watts per channel, 60V
When driving a 70 V line up to 450 Watts the actual Wattage is 74 % of the tap Wattage which results in a 1.3 dB lower than the maximum level.

When the load approaches 830 Watts, the actual Wattage is 67 %of the tap Wattage which results in a 1.7 dB lower than the maximum level.

Pro-Lite 5.0
4 Ohm 1500 Watts per channel, 77 V
8 Ohm 825 Watts per channel, 81 V
If a limiter is used to limit the output to 70V, it could be used for 70V system
Using it to drive a 100V system results the actual Wattage that is 66 % of the tap Wattage which results in a 1.8 dB lower than the maximum level.

Pro-Lite 7.5
4 Ohm 2450 Watts per channel, 99 V
8 Ohm 1425 Watts per channel, 106 V
Each channel could drive a 100V system directly but depending on how heavily you load the amplifier, it would be a good idea to use a limiter to limit the output voltage to 100V.

So now that we have some of the basics out of the way, let's look at some common questions:

Q: When I purchase speakers, should I buy "70V speakers"?
A: Buying speakers with built-in transformers is very convenient. The transformer Wattage is matched to the speaker. However, there are times when the speaker that best suits your needs does not come with a CV transformer. Purchasing a separate transformer solves this problem.

Q: How do I determine which Wattage tap to use?
A: The speaker receives the power indicated on the selected tap when the amplifier output reaches its rated output voltage. This is really no different than a low impedance system except that the power the speaker receives depends on the transformer tap instead of the amplifier power rating. Consider the speaker efficiency and sound level requirements to determine Wattage required. You may be surprised that when the speakers are close to the listener, a little power goes a long way. Also remember that it is now easy to set speakers at different volumes as required.

Q: Does the total of Wattage of the load, need to match the output power of the amplifier?
A: No. The Wattage of the load should be less than or no more than the amplifier rating.

Q: I see transformers in various sizes and prices. What are the differences?
A: Like many things in life, quality most times has a price. Transformers are not completely loss-less. Better transformers will have a lower insertion loss (less than 0.5 dB) whereas, inexpensive transformers may have losses greater than 2 dB (3 dB would lose half the power in the transformer).   Just like in our wire loss example above, heavier wire in the transformer produces less loss but more cost.

Higher Wattage transformers require more steel and copper to handle the increased current and magnetic field, so they are typically larger and more expensive.

The amount of steel and its magnetic quality also affects the transformer's low frequency limit at rated power. If this limit is exceeded, the transformer saturates and appears as a short circuit to the amplifier (not a good thing). So high-pass filtering is recommended in all constant voltage systems (most constant voltage amplifiers have them built in, but it is best to make sure). A better transformer will have a lower frequency limit and should be used when low frequency reproduction is important.

Transformers can have a single Wattage primary or have multiple taps.   Multiple taps are more convenient but can cost more.

Q: Some constant voltage amplifiers have output transformers and others have direct outputs, what difference does this make?
A: There are several differences in operation of systems with direct verses transformer isolated outputs. For many years most all constant-voltage amplifiers had transformer isolated floating outputs. This has several advantages. Since the speaker line is floating (not referenced to ground), the system continues to operate if one conductor of the line shorts to ground. (this hopefully will never happen) In most commercial buildings the structure is grounded steel so if the wire is run across sharp things in the ceiling, a short to ground could be the result. Although this is never a good thing at least the system will continue to operate until fixed.

A transformer output that is balanced greatly reduces the radiation of the speaker line into other things (mic lines, telephone line). The down side of such a system is the increased cost, the additional power loss and a somewhat limited low frequency response.

A direct output system can be singled ended, (one side is grounded) or bridged (balanced). For higher Wattage applications, a conventional amplifier of the correct Wattage can be used. For example, an amplifier that produces 612 Watts into 8 Ohms (1224 Watts into 4 Ohms) will produce a 70V output. But in this case, using an even larger amplifier is not better.   The maximum output voltage will increase above 70V and unless CV system is designed for this elevated voltage, transformer saturation can result.

Q: Most distributed speaker systems (speaker systems that rely on many speakers spread evenly through the room instead of a single speaker or cluster) use a CV system to connect the speakers to amplifier. Is there another way to build this type of system?
A: Yes. With careful design, a system using conventional 4 or 8-Ohm speakers can be connected to a conventional power amplifier but the wiring is more complex. To begin with, all of the speakers must be identical.   The number of speakers used is an important part of the design, as you will see when we look at the math involved. Connecting speakers of the same impedance in parallel divides the impedance by the number of parallel connections. So wiring two 8-Ohm speakers in parallel results in 8/2 = 4 Ohms. If we do this twice and then connect the resulting 4-Ohm pairs in series we now have an 8-Ohm load. (The impedance adds for a series connection.) To do a larger system you continue this approach of parallel connecting speakers that are then series connected. These resulting sub systems can then be parallel-series connected. Because the impedance is low, heavy gauge wire must be used. Each sub-system that is series connected must be the same to keep the power in each speaker the same.

Q: Beside the obvious, what are the differences between using a 70.7V or 100V system and are there special transformers for each.

A: Because the voltage is higher, the wire loss in a 100V system is less but the wiring requirements are more stringent. Be sure to check your local electrical code.
For the same load impedance, a 100V drive produces 3 dB more output or twice the power as when driven with 70.7 Volts. There is no magic here, the ultimate power is determined by the amplifier. Although there are transformers designed for each application the only real difference is if you use a transformer with Wattage markings for 70V, the power will be twice the rating when connected to a 100V drive. For example, the 5 Watt tap on a 70V transformer will deliver 10 Watts on a 100V system.
WARNING: If using a 70V transformer on a 100V line, **NEVER** use the highest Wattage tap. The transformer delivers its maximum power on the next lower tap, assuming it is 1/2 the Wattage.

Conclusion

So as we have seen there is no real mystery to Constant Voltage distribution systems. They offer significant advantages in applications requiring many speakers over a large area. The quality of such a system can be very good if appropriate speakers are used with transformers that have a low insertion loss and a frequency response suited to the situation. Much of the common perception of low quality comes from systems that use inexpensive speakers and transformers. Low impedance systems with the amplifiers located close to the speakers have a definite advantage in most cases, but constant voltage distribution systems have their place and can solve design challenges.

Although the cost can be higher than a couple of speakers mounted on the wall at the end of the room, installing a distributed sound system in large areas or areas with low ceilings can be a good solution. Distributed sound systems can be less prone to feedback, and provide a more uniform sound level throughout the room.

Here is the Math

For those that want to see how the numbers were arrived at in the example and do calculations for your own situations, here is the procedure.
The losses are most easily determined if we measure them in dB. The actual dB can be easily totaled and the loss in dB is actually very informative. Once we have the loss in dB, it can be converted to determine actual power losses.

Loss of signal in the speaker wire for 4 and 8 Ohm speaker loads

Use the tables below to determine the loss in dB.
Wire loss: Wire Gage vs Distance for 8 Ohm Load

	Feet	50	100	200	300	400	500	600	700	800
Guage	Ohms/Ft	dB	dB	dB	dB	dB	dB	dB	dB	dB
8	0.001209	0.07	0.13	0.26	0.39	0.51	0.63	0.75	0.87	0.99
10	0.002036	0.11	0.22	0.43	0.64	0.84	1.04	1.23	1.42	1.61
12	0.003238	0.17	0.34	0.68	1.00	1.30	1.60	1.89	2.17	2.44
14	0.00515	0.28	0.54	1.05	1.53	1.99	2.42	2.84	3.23	
16	0.00819	0.43	0.85	1.62	2.33					
18	0.01302	0.68	1.31	2.44						

Table 2

Wire loss: Wire Gauge vs Distance for 4 Ohm Load

	Feet	50	100	200	300	400	500	600	700	800
Gauge	Ohms/Ft	dB	dB	dB	dB	dB	dB	dB	dB	dB
8	0.001209	0.13	0.26	0.51	0.75	0.99	1.22	1.45	1.67	1.88
10	0.002036	0.22	0.43	0.84	1.23	1.61	1.97	2.31	2.65	2.97
12	0.003238	0.34	0.68	1.30	1.89	2.44	2.95			
14	0.00515	0.54	1.05	1.99	2.84					
16	0.00819	0.85	1.62	2.98						
18	0.01302	1.31	2.44							

Table 3

Loss of signal in the speaker wire for 70V and 100V systems

The dB loss of signal in the wire can be calculated using the follow equation:
Loss dB = 20 log (RL /RL+RW)
Where:
RL is load resistance (See table 1)
RW is wire resistance = wire resistance/ft from table * number of feet.

Transformer losses examples.
AutoMatch II = 0.4 dB
24 Watt transformer sample 0.7 dB
10 Watt transformer sample 0.43 dB

Once you have loss in dB, this is the actual reduction is sound level from what the loss-less level would be. Determine total Wattage loss is calculated by:
WL = Wa * (10^(-LdB/10))
Where:
-Ldb is the loss in dB
WL is Watts into load
Wa is the Wattage delivered from the amplifier