# Understanding and Working with Distributed Sound Systems

***by Larry Benedict***

The need to distribute power amplifier output using small gauge wire to a large number of speakers is commonly encountered in paging and background music distribution systems in large facilities such as office buildings, schools, hospitals, factories, etc. Constant voltage audio systems were developed in the early 20th century as a way of distributing audio from a power amplifier to multiple loudspeakers in an efficient and economical manner.

The most common voltage encountered in the U.S. is 70.7 volts, commonly referred to as 70 volt. In Europe 100 volts is the most common. While the 70.7 volt system is standard in the U.S., 100 volt systems are becoming more common as recent changes in the National Electrical Code (NEC) allow up to 100 volts (power limited) to be run out of conduit. It is important to note that state and local codes ultimately determine how systems can be wired. Consult your local code officials when in doubt about codes. A good example of code differences is in the Eastern U.S.. There 25 volt systems are commonly found in public buildings such as schools and hospitals because that is the voltage specified in their local codes. While this discussion will use the 70.7 volt system as the example, all of the concepts apply to any constant voltage system regardless of the specified voltage.

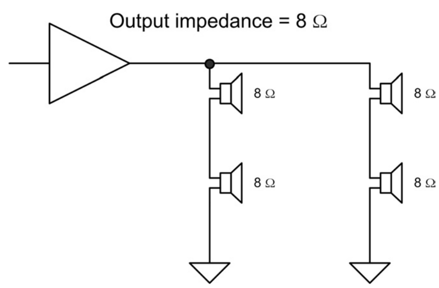


Figure 1— Low impedance system example.

The term constant voltage is often misunderstood. It does not mean that the voltage stays at a fixed amplitude at all times. What it means is that the system can produce a maximum voltage of, in this case, 70.7 volts root-mean-square (rms) when the amplifier is driven by a sinewave to a maximum output of 100 volts peak. This output voltage is independent of the load as long as the load does not exceed the amplifier's maximum power rating. During normal operation the system's voltage will vary in amplitude as the signal source varies in amplitude. However, the instantaneous voltage in the system will remain constant as loudspeakers are added or subtracted from the system as long as the system does not see a load in excess of the power amplifier's rating.

Figure 1 illustrates a typical low impedance system. If we consider the typical method of using an amplifier designed to drive low impedance devices such as 8 ohm loudspeakers directly, we will quickly find out that while it is possible to use a combination of series-parallel connections to achieve acceptable impedance, the amount of current draw is very large. This large current draw will require large gauge wire to be used for anything but extremely short distances. Herein lies the problem when this method is used to distribute audio to loudspeakers positioned far away from the amplifier.

## Basic Theory

The constant voltage method works in much the same way as how the power company delivers power to our homes. A typical home in the U.S. has power brought to it via relatively small wires, which carry thousands of volts of electricity at a comparatively small current. Shortly before the power is brought to the house, the high voltage is stepped down through a transformer to a relatively low voltage at a comparatively higher current. The loads in the house might be the television, toaster and lights. All consume different amounts of power (watts), but they all see the 120 volts delivered.

Figure 2 illustrates how a typical constant voltage system might be constructed. In a constant voltage audio system, an amplifier designed to drive a constant voltage system amplifies the audio. The output of the amplifier is connected to a relatively small wire, which is then connected to a primary tap on a transformer whose secondary is connected to the loudspeaker. The number of windings used on the primary determines how much power is transferred to the loudspeaker. Normally the primary transformer taps are labeled in watts with the larger number of windings resulting in a

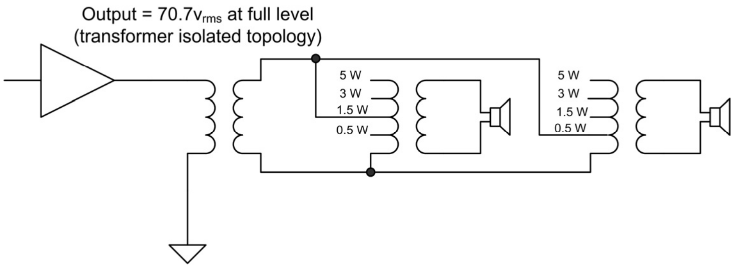


Figure 2— A typical constant voltage system.

higher number of watts being delivered to a given loudspeaker and thus increased output from that loudspeaker. Sometimes there are also multiple secondary taps for loudspeakers of various impedances. These secondary taps are typically labeled in ohms.

The amplifier used in Figure 2 is connected through a transformer, which provides isolation of the amplifier from the line being driven. This is the traditional method employed in constant voltage systems. The output transformer is typically either internal to the amplifier or connected on the back of the amplifier. Other amplifier output topologies

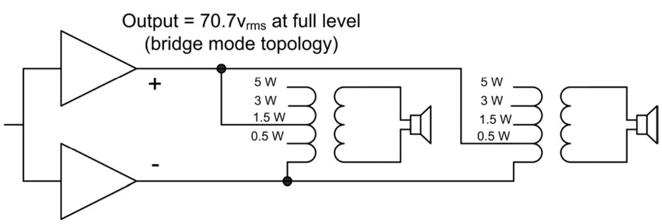


Figure 3—Constant voltage using bridged output.

exist for driving constant voltage systems. Figure 3 illustrates the use of two amplifier outputs in a bridged configuration. It is important to note that not all amplifiers are designed to operate in a bridged configuration and even if they are, they may either not be capable of providing enough output voltage or may provide too much voltage. Another amplifier output topology is illustrated in Figure 4. This direct drive method is probably the latest method of creating a constant voltage system. These amplifiers typically are much smaller and lighter due to the class of operation used for amplification and resultant reduction in power supply size. The direct drive topology has sparked some controversy. Critics of this output topology argue that part of the ruggedness of constant voltage systems comes from the transformer isolation afforded to the system's amplifier(s) and that direct drive amplifiers lack this transformer isolation, thus possibly making them more prone to damage or total shutdown when the loudspeaker line being driven has faults on it.

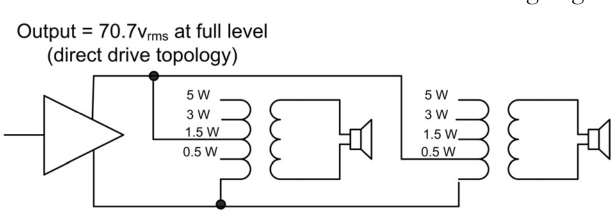


Figure 4—Constant voltage using direct drive output.

## Audio Quality Issues

One of the most common complaints with constant voltage systems is their lack of fidelity and frequency response when compared to low impedance systems. This is due to a number of factors. One such factor is that the transformers typically used in a constant voltage system do not have good frequency response characteristics. Another problem encountered with transformers is that the less expensive ones do not behave well at low frequencies. All transformers exhibit very low impedance at low frequencies, but the low cost transformers typically have very poor performance in this area. Another is that these systems are typically designed as cheaply as possible, so high quality loudspeakers are not used and the number of loudspeakers used are not in sufficient quantity to provide for even coverage.

Over the last ten or fifteen years this has become less of an issue with improved loudspeaker and transformer designs/technology coupled with a change in the client's business climate making more expensive systems acceptable if not necessary.

## Simplified Design

Designing constant voltage systems is not complicated. Although it can be made complicated if you insist on proving everything out by Ohm's law, etc.

Simply calculate the amount of power required by each loudspeaker and/or paging horn in order to obtain the desired SPL. If you are in doubt on how to do this, there are programs such as the EV ceiling speaker calculator that can help you make these design determinations. Once you have the total power consumption for each device, add those together to determine the total amount of power needed in theory. I say in theory because in the real world there are other losses to take into account such as those from wire resistance, transformer insertion loss, increased power draw as a result of frequency dependent impedance variations, as well as, the material being reproduced by the system. Typically you want to add a safety margin of usually between 20% and 50% to your total theoretical power requirement.

For a system that is primarily used for paging and light background music applications 20% would probably be sufficient. For a foreground music system you might want to have a margin of 50%. As a general rule, the lower the crest factor or loudspeaker/transformer quality, the more safety margin you should have. Easy listening and adult contemporary music, while compressed and of a relatively low crest factor, is not as extreme a case as heavy metal or techno/electronic music. To find the actual power needed multiply the total theoretical power by the desired safety margin and then add that to the total theoretical power number.

***Example #1***

*A particular building has an office space that is covered by seven ceiling speakers each tapped at 1.75W each and four paging horns in the warehouse each tapped at 15W. What is the total power required by the system assuming a 20% safety margin?*

*First calculate the theoretical power:*

$$P_{Theoretical} = 1.75W \times 7 + 15W \times 4 = 12.25W + 60W = 72.25W$$

*Next, calculate the additional power required by the 20% margin:*

$$P_{Safety} = P_{Theoretical} \times 20\% = 72.25W \times 0.2 = 14.45W$$

*Lastly, calculate the total power required:*

$$P_{Total} = P_{Theoretical} + P_{Safety} = 72.25W + 14.45W = 86.7W$$

An Electro-Voice MA-1212 amplifier is rated for 120 W nominal. With a load of approximately 87 W this amplifier would be a good choice for the above situation and leave some room if additional loudspeakers needed to be added or if some tap settings had to increase.

## A Word on Wire

Once you know the total power requirements and have determined the type and size of amplifier you will use, the next question to be answered is what kind of wire should be used. There are many things to consider. First is the load itself. Typically we want no more than 1.5 dB of loss to occur due to wire resistance. You overcome wire resistance with bigger wire, but remember one of the main reasons constant voltage systems are popular is because of the reduction in wire size needed. Consulting Table 1 will give you an idea of the minimum size of wire needed. However, before making a final decision you should ask yourself if there is a reasonable chance that this particular circuit will be added to at a later date. If so, you may want to increase wire size to enable you to add additional loudspeakers and/or horns to the wire run in the future. Remember that you will be expending a fair amount of labor in pulling this wire. It would be less costly in the long term to avoid having to pull a new run or replace the existing run.

Another thing to consider is if this wire will be run in a plenum or non-plenum space. A plenum space is any space, such as a drop ceiling or raised floor, that acts as a return air duct for the HVAC system. In such spaces only plenum rated cable may be used. You can identify the cable type based on the markings printed on the cable jacket: CL2P, CL3P, and CMP are all plenum rated cable types (the "P" designates them as such). When in doubt about which type of cable to use and how it must be installed consult your local code officials. Once you know the local cabling requirements you need to meet for a given installation your wire supplier can help you in selecting the proper cable. Many contractors make it a policy to use only plenum rated cable for all wiring in order to avoid any rework due to code restrictions.

Lastly, no matter what the size and plenum rating of the cable, you should always use stranded, twisted pair cable. You should use stranded simply because it is much easier to work with especially on long pulls and with respect to making connections. You should use twisted pair to avoid cable crosstalk as much as possible. Crosstalk occurs when two cables lie adjacent and in close proximity to each other for long distances. While it does not entirely prevent crosstalk, twisted pair cables certainly have much more immunity to it.

## Test and Verification

There is one last step to complete before making the final connection to the amplifier. You should make a quick measurement of the line(s) with an impedance meter to make sure that the installation has been done properly and that the amplifier(s) will not be at risk of damage due to either a shorted line or too heavy a load caused by improper taps. This is particularly important if you or your company was not responsible for the entire installation of the system. This is commonly the case when the general contractor or the primary electrical contractor on a job insists on using their labor wherever possible. General electricians, while good at pulling wire, are not necessarily as educated about the devices they are hooking up. It is not uncommon to find bad splices, incomplete runs, and especially improperly tapped loudspeakers and horns.

An impedance meter is a meter that is specifically designed to measure the impedance (AC resistance) of a device or network of devices. An impedance meter should not be confused with a multimeter. A multimeter is a device that is designed to measure DC resistance only. Impedance meters can be used to not only measure the impedance of a constant voltage system, but can be used to measure loudspeaker coils and can be used to help determine the values of some inductors and capacitors such as those found in crossovers—with a little math of course.

The quick and dirty method of figuring out what the measured impedance should be is to take the theoretical power requirement of the system and divide it into the square of the system voltage.

***Example #2***

*Using the example previously discussed, the theoretical total power was 72.25 W. The formula for impedance is $Z = E^2 / P$. Most people will simply use 5000 in place of the square of the voltage for a 70.7 V system. The reason being is that 70.7 V squared is 4998. It's easier to remember 5000. But for the purists we will use the actual numbers.*

$$Z = (70.7\ V)^2 / 72.25\ W$$
$$= 4998\ V^2 / 72.25\ W$$
$$= 69.18\ \Omega$$

This is the quick and dirty method because impedance varies with frequency. Figure 5 is an example of the impedance curve of a constant voltage loudspeaker at its 60 W tap. Due to variances caused by the voice coil of the loudspeaker, transformer, and effects from the loudspeaker enclosure, the impedance changes depending on the frequency.

**Recommended Wire Lengths in Feet (Approximately 1dB Loss)**

| Wire Size | Power (70.7V System) | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| AWG | 4W | 10W | 20W | 40W | 100W | 200W | 400W | 1000W | |
| **22** | 4101 | 1640 | 820 | 410 | 164 | 82 | 41 | 16 | **Feet** |
| **20** | 6562 | 2625 | 1312 | 656 | 262 | 131 | 66 | 26 | **Feet** |
| **18** | 13123 | 5249 | 984 | 1312 | 525 | 262 | 131 | 52 | **Feet** |
| **16** | 19685 | 7874 | 3937 | 1969 | 787 | 394 | 197 | 79 | **Feet** |
| **14** | 32808 | 13123 | 6562 | 3281 | 1312 | 656 | 328 | 131 | **Feet** |
| **12** | 52493 | 20997 | 10499 | 5249 | 2100 | 1050 | 525 | 210 | **Feet** |
| **10** | 78740 | 31496 | 15748 | 7874 | 3150 | 1575 | 787 | 315 | **Feet** |

Table 1—Maximum run length based on power and wire size.

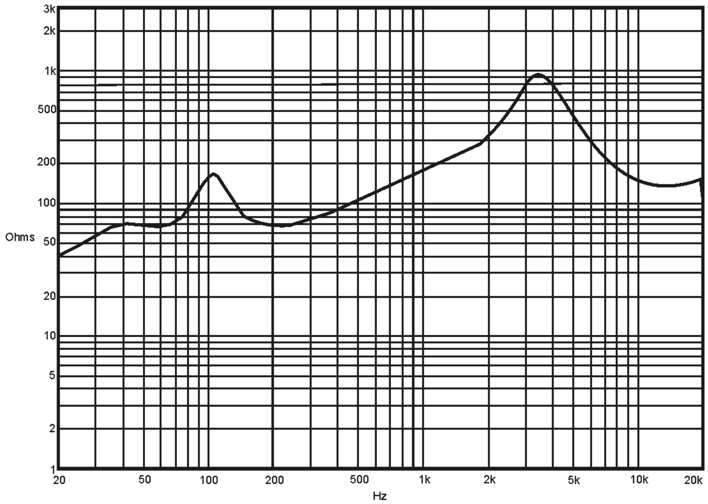


Figure 5—Real-world impedance response.

Figure 6 depicts two of the most popular impedance meters. The unit on the left is a very modern design that can test at various frequencies and thus give a better picture of what the actual impedance of the device or network may be. In addition it can automatically calculate the anticipated load in watts. The meter on the right is an example of a meter that measures at one fixed frequency, in this

Figure 6—Popular impedance meters.

case 1 kHz. Most constant voltage loudspeakers and horns have their impedance or power taps specified at either as nominal or at 1 kHz. Many loudspeakers and horns have impedance or power consumption plots provided in their data sheets. This enables the installer, when equipped with an impedance meter such as the one on the left of Figure 6, to make accurate measurements at various frequencies.

### Final Connections and Tuning

Once acceptable measurements have been achieved, the final connections to the amplifier can be made and the system adjusted for proper SPL. The amplifier should not indicate clipping under normal program conditions. Make sure that any increase in tap settings does not overload the amplifier. Also make sure that any equalization added does not cause excess load on the amplifier.

Most constant voltage systems should have at least a 6 dB/octave if not 12 dB/octave high-pass filter with a cutoff frequency no lower than 100 Hz before the amplifier in order to prevent excessive low frequency energy from reaching the transformers. Failure to do so can result in excessive current draw due to low impedance. With that in mind, you should watch out for any boost equalization at 200 Hz and below. Many systems have been brought to failure by excessive low end boost EQ. If enhanced low-end response is desired, a constant voltage loudspeaker or subwoofer designed specifically to meet low-end response criteria should be considered at the design stage.

Lastly, a properly set limiter before the amplifier input is a good idea as well.

### Further Study

For additional information on the design and installation of constant voltage systems consult the following:


- Davis & Davis, *Sound System Engineering, 2nd Ed.* (Focal Press, 1997)
- Giddings, *Audio System Design and Installation* (Focal Press, 1990)
- Davis & Jones, *The Sound Reinforcement Handbook, 2nd Ed.* (Hal Leonard, 1989)
- Lampen & Chapman, *Audio/Video Cable Installer's Pocket Guide* (McGraw-Hill, 2002)


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