HIGH IMPEDANCE LOUDSPEAKER BASICS
September 2014

One Systems offers most of its high performance direct weather loudspeaker systems with a "transformer" or "high impedance" option. One Systems models use a variation of a transformer known as an autoformer. Additional details and important information regarding autoformers can be found on page 4 of this document.

These loudspeaker systems are often referred to by various names such as 70 volt systems, 100 volt systems, high z systems, high impedance systems, or transformer systems. These systems are often referred to as "constant voltage" systems although there is nothing "constant" about the voltage. The design simply raises the output voltage to either a maximum of 70.7 Vrms or 100 Vrms and then matches that increased voltage in the increased input impedance associated with the transformer primary windings. This is done in order to reduce the current in from the amplifier to the transformer/autoformer primary. Reducing the current can substantially reduce the line losses and provide more power for the loudspeaker.

In a conventional, or low Z, loudspeaker design the impedance of the loudspeaker is typically rated at a nominal impedance of either 8 ohms or 4 ohms. All modern power amplifiers are rated to a specific output power into either a 4 ohm or 8 ohm load. As an example, consider a situation where we wish to deliver 300 watts to a 4 ohm nominal load. When a 4 ohm loudspeaker is connected to the amplifier and driven to 300 watts the amplifier will have a 34.6Vrms voltage measured across it's output terminals and have an 8.65 amp current output. So far this example is very straightforward. However, we have not considered the additional impedance (resistance) associated with the cable that we used to connect the loudspeaker to the amplifier. We basically connected the loudspeaker with magical ZERO loss wire! So we need to re-calculate with actual wire and see what happens.

If we used AWG16 wire (area of 1.31mm^2) and locate the loudspeaker 20 feet (6.1 meters) away from the amplifier we discover that this length of wire will have approximately 0.16 ohms of resistance that we must add to the total impedance that the amplifier "sees". So the total impedance that the amplifier must drive now becomes 4 ohms plus 0.16 ohms, or 4.16 ohms. (The AWG 16 wire is 4 ohms per 1000 ft (305m)). The loudspeaker is 20 feet away but the wire must get to the speaker and then back to the amplifier, so the total distance is 40 feet which calculates to 0.16 ohms)

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The original calculation yielded 300 watts with the total load of 4 ohms (the value of the loudspeaker impedance when connected with wire that had no resistance) but since our "real world" example has 4.16 ohms of total impedance we see that the power (using ohms law and standard power calculations) has now dropped to 287.7 watts and the current has dropped to 8.31 amps. But now we also must remember that the wire resistance will produce some power loss so the calculation reveals that there is approximately 11 watts of loss on the wire, so we only have 276 left at the loudspeaker.
A quick summary shows that our example of 300 watts has quickly become 276 watts at the loudspeaker.

Now, let's move the loudspeaker 330 feet (approximately 100m) away from the amplifier and still use AWG 16 wire. Again, because we need to get the wire to the speaker, and then back to the amplifier, we have 660 feet (201m) of wire. This length of wire will have a 2.64 ohm resistance. We must now add the 2.64 ohms of wire resistance to the loudspeakers 4 ohm nominal impedance. We now have 6.64 ohms of combined wire and loudspeaker impedance. Since our amplifier is producing a 34.6 volt signal we see that the total power the amplifier can supply is now reduced to 180 watts. (a long way from the original 300 watts). But, worse yet, we see that the current has dropped to 5.2 amps. Using the known voltage of 34.6 and the new current of 5.2 amps we can calculate the power loss on the 660 feet of wire (from amp to speaker and back to amp). We discover that out of the total available power of 180 watts, a full 71.4 is lost in the wire and only 108 watts are available for the loudspeaker.

If we need to drive the loudspeaker with 300 watts we need to increase the amplifier output to 498 watts (57.7 volts) if we use AWG 16 wire.

The above example is very typical and illustrates the substantial loss of power found in many public address/sound reinforcement systems when the loudspeaker is some distance from the amplifier. There are basically two solutions to this problem. The first solution is to use much larger wire. If we use AWG 12 wire (area of 3.31mm^2) we see the wire resistance has dropped from the 2.64 ohms of the AWG 16 wire to 1.05 ohms. We add this to the loudspeaker impedance and see that we have 5 ohms of total impedance and our amplifier can now produce 239 watts instead of the 180 with the smaller AWG 16 wire. The wire loss is now 47.6 watts (compared to the 71.4 lost in the AWG 16 wire) and there are now 190 watts of power available for the loudspeaker. Of course even larger wire will reduce the losses further.

It is important to state that there is really no substitute for LARGE copper wire. It is expensive and often difficult to run long distances but from a performance standpoint, there is no substitute!

A second alternative that is commonly used in the professional sound reinforcement industry is to use a "high impedance" or line matching transformer design.

The basic configuration is to add a transformer or autoformer between the amplifier output and the loudspeaker crossover terminals. This transformer is usually added inside the loudspeaker itself and is "inserted" in the circuit path between the loudspeaker inputs and the passive crossover

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inputs. The basic function of the transformer/autoformer is to increase the input impedance that is presented to the amplifier. When the input impedance is increased the amplifier current draw is reduced. When the amplifier output current is reduced the power loss associated with the cabling is reduced (reduced I^2 R losses). The transformer then reduces the voltage and increases the current and presents this increased current to the loudspeaker components.

For this example we will select a loudspeaker system that uses a European 100 volt standard.
It is common for transformer based loudspeaker designs to have multiple power taps. In this example we will select a 100 volt transformer with power taps at 300 watts, 150 watts, and 75 watts. The assumption when wiring the transformer is the if we supply a 100 volt potential across the output of the amplifier and connect to a “high z” transformer system with a rated power tap of 300 watts we will “get” 300 watts of power delivered to the transformer.

As noted above, transformers are basically impedance converters. So in this example if we have a 100 volt potential and wish to have 300 watts we will need a loudspeaker impedance of 33.3 ohms. (This is the impedance that the amplifier will “see” and deliver the appropriate current level. The transformer will then convert the voltage and current levels so that the internal loudspeaker components, which are still 4 ohms, will see the appropriate voltage and currents to produce 300 watts, at least theoretically!)

Now, let’s connect this “high z” loudspeaker up to the same 330 feet of AWG 16 wire from our first example. We still have 2.64 ohms of wire resistance to add to the equation. Our loudspeaker input impedance is now 33.3 ohms and after we add the 2.64 ohms of wire resistance we have a total impedance of 35.97 ohms. With the 100 volts of output we now have 278 watts of power output from the amplifier. (We calculated 300 but that was before we added the resistance of the wire!)

We have 2.78 amps of current in this situation and find that we have 20.4 watts of power lost in the wire and can deliver 257.3 watts of power to the loudspeaker. Note that this is still not the 300 watts that we expected but if we compare to the “low z” example we have 257 watts, compared to 108 watts when we used a 4 ohm low impedance loudspeaker with the same 330 feet of AWG 16 wire. So far the high impedance alternative looks very good when long wire runs are required. However, we must also consider the losses that occur inside the transformer as the signal is converted from high voltage/low current to the lower voltage/higher current conditions required for the loudspeaker. These losses are referred to as insertion losses. All transformers have insertion loss but higher quality transformers can minimize these losses. So, for this example we will select a very high quality transformer and assume an insertion loss of 0.6dB. Using the 0.6dB insertion loss we find that the 257 watts of power that were delivered to the transformer are now reduced by insertion losses to 224 watts. So we actually have 224 watts available for the loudspeaker. In this example, the high z loudspeaker system offers a clear advantage over the low impedance design.

When using the high z, or transformer based system we must also remember that there are always low frequency response limitations and distortion effects when we apply low frequency signals near the rated power limit of the transformer. For this reason the transformer system requires a high order high pass filter to remove low frequency signals. This high pass filter is inserted in the system prior to the amplifier and will prevent damaging low frequency material from being presented to the transformer. All good systems manufacturers will recommend a high pass filter and can usually recommend the correct high pass filter corner frequency.

So we see that there are certainly applications where high z designs can offer superior performance but we also see that those high z designs require special attention if they are to perform as expected.

A LITTLE MORE ABOUT TRANSFORMERS

In the professional audio industry there are two types of “transformers” used in high impedance systems. The two types are: “traditional transformers” and “auto transformers, usually called “autoformers”.

Transformers have two sets of independent windings, known as a primary and secondary.

NOTE: If a technical specification requires electrical isolation between the source and the load a transformer MUST be used. (NOT AN AUTOFORMER!)

Autoformers are similar to a transformer but instead of using two separate windings they employ a single winding with taps at specific locations to provide either step up or step down conversions.

Auto Transformers, or Autoformers, can offer high bandwidth and better low frequency response as well as lower insertion loss then conventional transformers of the same size. One Systems utilizes autoformers for all of its loudspeaker models (104HTH, 106HTH, 108HTC, 108HTH, 208HTC, 112HTH, and CFA-2HTH). A high quality autoformer can offer excellent performance but it must be noted that there is no source to load electrical isolation. Autoformers are an excellent choice for high performance applications, particularly for very high power applications and are used by many pro audio manufactures. Autoformers are fairly common in high power applications and are routinely used for high performance applications.

NOTE: Autoformers do NOT provide source to load electrical isolation. If a technical specification requires source to load isolation an autoformer CANNOT be used!

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WHEN TO USE TRANSFORMER (Autoformer) BASED LOUDSPEAKERS

Choosing whether to use a low Z loudspeaker system or a transformer based hi z system can be a difficult decision.

A. **Multiple loudspeakers to a single amplifier channel**

If multiple loudspeakers are to be connected to a single amplifier channel the following considerations should be taken into account.

1. If the amplifier is capable of driving a 2 ohm load then a maximum of 4 loudspeakers rated at 8 ohms may be wired in parallel on each channel. (or a maximum of 2 loudspeakers rated at 4 ohms). There are many possible series-parallel configurations but this wiring is not recommended as a failure on a loudspeaker in the configuration will cause other perfectly good units to stop working because of the open circuit.

2. If the amplifier is capable of driving either a 70.7Vrms or 100Vrms output then high z loudspeaker may be used. In this situation the loudspeakers are all run in parallel and the sum of all the loudspeaker power taps used should not exceed the amplifiers power rating per channel.

If the high z loudspeaker is used then high pass filtering (low cut) is necessary. Additionally, insertion loss of the transformer must be considered as well as actual power delivered to each loudspeaker due to line losses.

B. **A Single loudspeaker at a great distance**

1. If a single loudspeaker is a great distance* then a comparison must be made (as in the examples above) of line losses in the wire (low z) versus losses associated with both the wire AND transformer insertion loss.

*** NOTE:** The term “great distance” is completely relative. In all situations analysis is necessary to determine the most optimized operating conditions. There are situations where large wire sizes will outperform transformer based designs.

APPENDIX 1

The table below lists transformer (autoformer) primary impedances for various power tap values for both 70.7V and 100V operating voltages

	70.7 Vrms	100 Vrms
600W	8.3 (Ohms)	16.6 (Ohms)
300W	16.6	33.3
150W	33.3	66.6
75W	66.6	133
37.5W	133	266
18.75W	266	533
9.37W	533	1066

Note that in the above table the 70.7 Vrms transformer/autoformer system presents a primary impedance of 8.3 ohms for the 600 watt tap. It makes no sense to use a 70 V high impedance transformer enclosure at 600 watts if the low z enclosure impedance is 8 ohms. (And it barely makes sense if the low z impedance is 4 ohms!) However, it makes much more sense if the 100V version is used for the 600 watt tap!

We see a “practical” limit to where high z systems make sense, particularly in the 70 V designs at 600 watts. When the transformer insertion losses are added in a 600 watt tap for 70 v operating voltage is always outperformed by a low z design, regardless of the line resistance. At this point a good question would be….”so why does One Systems offer this tap value?” Our recommendation is to not use this tap but it does have value in the 100V operating voltage configuration.

One Systems also offers an “on line” calculator that can help evaluate the suitability of high impedance or low impedance designs based on input parameters such as wire length, wire gauge, required power etc. This calculator can be found at :

http://www.onesystems.com/impedance-calculator.php