MODEL SOUNDS INC.

R/C Models Like You've Never Heard Them Before!

Practical Limits on SPL (Sound Pressure Level) Achievable in R/C Model Aircraft

David Harrison

Model Sounds Inc.

Date: April, 2019

This article discusses the achievable SPL (Sound Pressure Level)s that are achievable in R/C model aircraft (airplanes and helicopters) using the best technology available at the time of writing.

CURRENTLY ACHIEVABLE SPL LIMIT

Using the best available loudspeaker technology and modern, high efficiency Class D audio amplifiers, a practical, readily achievable SPL on moderately sized model aircraft (e.g. 6-7ft wingspan) is about 106-107dB.

Higher levels of a few dB more are achievable in giant scale airplanes capable of carrying heavier or more loudspeakers, a heavier and more powerful amplifier and a larger battery.

However, as explained below, increasing SPL by increasing amplifier power and consequently higher power loudspeakers and battery, is a losing game as the increase in SPL is only small for a large increase in weight.

WHAT ARE THE FACTORS PREVENTING A MUCH HIGHER SPL?

In a model aircraft, the overriding factors are weight, loudspeaker sensitivity and amplifier size and efficiency.

Loudspeaker Sensitivity

Modern cone loudspeakers, of a practical size, e.g. 4 inches (100mm) diameter, to be carried in R/C model airplanes or helicopters, have a sensitivity rating of as high as 90dB/1W/1m. What this rating and units mean is that at a distance of 1m, (and on-axis), with an audio electrical input of 1 Watt rms (root mean square), the SPL will be 90dB. SPL is measured on a logarithmic scale where 0dB represents the quietest sound a human ear in good health can hear.

Because of this logarithmic scale, a doubling of SPL is represented by a 3dB increase, a quadrupling by an increase of 6dB and a ten-fold increase by 10dB.

So for a loudspeaker with a sensitivity of 90dB/1W/1m, if it is driven with a 10 Watts rms audio electrical signal, it will produce 100dB at 1m distance.

The value of 90dB/1W/1m is quite high and is rarely achieved. Many loudspeakers have sensitivities in the low 80’s dB/1W/1m. A very few loudspeakers have an even higher sensitivity, but are usually very large and heavy.

To give you an idea of how loud a 100dB SPL is, you can refer to sound pressure in Wikipedia and a bit further down that web page is a table giving the SPL from various sources. 100dB is the SPL given from a jackhammer at 1m which is very loud.

Now, if we were to increase that power delivered to the loudspeaker from 10 Watts by four times to 40 Watts, that would be an additional 6dB increase in power and since SPL is proportional to audio power, we would get 106dB. This is equivalent to four jackhammers at 1m, all hammering away in synchronism simultaneously!

Do Exciters/Transducers Help?

Exciters (also known as tactile transducers) have gained some popularity in the model airplane world due to their small size, light-weight and the fact that they do not require large holes to be cut in the airframe to let the sound out, as are required by conventional cone loudspeakers.

Unlike conventional cone loudspeakers, where the moving voice coil moves a paper or plastic cone which then moves the air to make sound, exciters do not have a cone, or a frame. Instead they are attached directly to a surface by means of double side adhesive tape. They then vibrate that surface directly to move the air to generate sound. Thus, the whole airframe can potentially radiate the sound. The problem with this is that in order to achieve comparable SPL's as conventional loudspeakers, the exciter must vibrate the airframe quite vigorously which can potentially lead to airframe stress and possibly compromise structural integrity when used over a long period of time.

Additionally, the SPL level and the tonal quality of the sound you get depends greatly on the material to which it is stuck. Factors such as thickness, stiffness, type of material, edge termination, and size of the material all affect the SPL and sound quality. Generally speaking, thinner, more flexible materials will produce higher SPLs but will lack low frequency bass tones. Thicker, stiffer materials will be quieter and will have better bass response. Thus using exciters in a model is a bit of a hit and miss affair with the end results for SPL and sound quality being very unpredictable.

The other issue with exciters is heat. Because of their small size, and hence low thermal mass, they get very hot, very quickly, since there is no metal frame or large magnet to act as a heatsink. They do have magnets, of course, but they are generally smaller than those used in conventional loudspeakers.

Tests conducted by several people on exciters have shown the overall SPL achievable using exciters to be around the same as that achievable using conventional cone loudspeakers.

Modern Amplifier Efficiency and Heat Dissipation

Modern audio amplifiers, that are not ultra-high-fidelity audiophile grade, all use Class-D amplification technology. This is a semi-digital technique that uses PWM (Pulse Width Modulation) to re-create the analogue audio signal to drive the loudspeaker. All modern Class D amplifiers have an efficiency of about 90%.

This means that, for a 40 Watts output to drive the loudspeaker, you have to supply about 44 Watts D.C. power input from the battery. The remaining difference of 4 Watts is dissipated as heat inside the amplifier chip.

The amplifier chip itself could not possibly dissipate that 4 Watts of heat internally, without overheating and destroying itself, so it has to pass that 4 Watts of heat into its outside environment by means of a thermal transfer pad, either underneath the chip or on top of it.

In order to keep the size and weight of the amplifier down, the thermal pad down approach is preferred whereby the PCB (Printed Circuit Board) copper planes act as a heat sink to dissipate that heat into the board itself and thence to the outside air.

When the PCB is small, i.e. only a few square inches, 4 Watts is about the absolute limit of heat dissipation, otherwise the board would overheat and every component on it could be damaged.

With a thermal pad up chip, a metal heatsink bolted to the board and in contact with the thermal pad is absolutely required. Whilst this does allow for higher levels of heat to be dissipated, and therefore a higher output power, the addition of the heatsink means a larger and heavier amplifier board.

Thus, the bottom line is this. For a small, lightweight, Class D amplifier, and current loudspeaker sensitivity of 90dB/1w/1m, a practical power output limit of 40 Watts from the amplifier can produce an SPL of about 106dB.

POSSIBLE OPTIONS FOR INCREASING SPL

1. ***Increasing Amplifier Power Output***
   Increasing amplifier power output means increased heat dissipation and increased power consumption from the battery.

   Increasing power output is really a no-win situation. Bearing in mind the logarithmic scale of SPL and human hearing, a doubling of power from 40 Watts to 80 Watts means an SPL increase of only 3dB, an increase which is only just barely perceptible. And a rule of thumb says that a perceived increase of a sound being “twice as loud” means an actual SPL increase of 10dB, or ten times.

That means to get a sound pressure level that seems to be twice as loud as 106dB, it would need to be 116dB, which would require a tenfold increase in output power to 400 Watts!

A 400 Watt audio power amplifier would be large, heavy and would require heatsinks and fans to keep its temperature to within tolerable limits.

Not to mention that you would then require a loudspeaker array capable of accepting 400 Watts of power which would make it very large and very heavy. And that's assuming it still has the same 90dB/1w/1m sensitivity level as before.

And last but not least, you'd also require a battery capable of delivering 440 Watts of power to supply both the 400 Watts of output power and the 40 Watts of heat lost due to the amplifier's efficiency not being 100%. And dissipating 40 watts of heat inside a model airframe is definitely not a very desirable state of affairs. Just think of how much heat is thrown off from an incandescent 40 Watt home light bulb!

2. ***Increasing Loudspeaker Sensitivity***
   Modern conventional cone loudspeakers have a range of sensitivities from 80-96dB/1W/1m.

   The loudspeakers we commonly use at Model Sounds Inc. have a high sensitivity rating of 90dB/1W/1m. Those loudspeakers are a very good compromise between the conflicting requirements of high power handling capacity, low weight, high sensitivity and low cost.

   Modern loudspeakers such as these are very inefficient – only about 1%. This means that even when we drive them with 40 Watts of audio electrical power from the amplifier, only 0.4 Watts comes out as sound energy. The remaining 39.6 Watts is dissipated as heat in the voice coil which is passed through the frame and magnet to the outside air.

   This very low efficiency is due to the mismatch between the moving cone's mechanical impedance and the air's mechanical impedance it is trying to move at its surface. "Mechanical impedance" (not to be confused with the 4 Ohms or 8 Ohms electrical impedance) is a measure of how "stiff" the medium is that the sound is travelling in, i.e. either air or the cone.

   Whenever you have an impedance mismatch in any mechanical/electrical system, you have a loss of energy and a poor efficiency in energy transfer.

The only loudspeaker technology available today which can partially overcome this is the horn loaded loudspeaker. This uses a relatively small cone that is relatively easy for the voice coil to move at the base of a parabolically shaped horn (similar to the old acoustic gramophone horns). The horn acts as a kind of impedance transformer which allows a much better match of the loudspeaker's mechanical impedance to the outside air's impedance.

Horn loaded loudspeakers typically have a sensitivity of 100dB/1W/1m. This is ten times that of the 90dB/1W/1m achievable using conventional cone loudspeakers, So, given a 40 Watts rms amplifier drive output, a horn loaded loudspeaker would be able to produce about 116dB SPL which is extremely loud.

However, the obvious problem with horn loaded loudspeakers is their physical size and weight. In short, in anything but huge giant scale model airplanes, horn loaded loudspeakers are simply impractical.

LOUDSPEAKER POWER RATINGS

Loudspeaker Power Ratings can be very misleading and many manufacturers will state claims such as XX Watts of "music power" or "peak power". They do this so as to claim higher power rating for their products than a continuous sine wave or "RMS" rating. For now, we do not need to know exactly what RMS or "Root Mean Square" means, but it is essentially the average of a steady sine wave signal. "Music Power" or "Peak Power" is much higher due to the peaky nature of a music or voice signal.

Many sounds used in R/C model sound systems are very repetitive and rhythmic such as engine sounds which also have a significant low frequency content (for the rumbling sound of the engine). When an engine sound is playing continuously, as it would be in most models, the power output is actually not all that peaky and is not far from the RMS value. Therefore, loudspeakers need to be chosen with an RMS, or continuous, rating that matches the rated power output of the ShockWave series sound module.

Power $P = V^2/R$ so as the voltage doubles, the power output will quadruple. This is why the power output on a 12 Volt supply is 10 Watts, but on a 24 Volt supply the power output can be as high as 40 Watts.

LOUDSPEAKER MECHANICS

We will describe briefly how a loudspeaker works and what the principle components are. The loudspeaker cone is attached to a ”voice coil” – a coil of several turns of wire around a tubular former that is attached to the cone. The coil is located in the gap of a powerful circular permanent magnet. Electric current flowing through the coil from the amplifier creates a magnetic force which causes the coil, its former and the cone to move in and out like a piston. The piston effect then pressurizes the air which we perceive as sound.

In order to make a loudspeaker sound louder, the air pressure that it creates – SPL or Sound Pressure Level – (measured in decibels above the threshold of hearing) has to be higher and so the cone must move more air and the cone excursion in and out has to be greater. This means the coil and magnet have to be deeper and the wire of the coil must handle greater current so it must be thicker wire. Therefore, the size of the magnet becomes larger, both in depth and diameter.

These are the basic laws of physics and cannot be circumvented. This is why a small 2” speaker can only handle a few Watts of power and why you cannot get a **LIGHTWEIGHT** 4 inch speaker that can handle much above 20 Watts.

There are 4” loudspeakers that can handle 40 Watts or more, but these are intended for car audio or home audio applications where weight is of no concern, so they have very large magnets and frames and are very heavy for their size.

Model boats and tanks generally do not have such stringent light weight requirements as do model aircraft and in many cases a model boat requires several pounds of ballast to get the waterline down to the correct level, so instead of adding lead dead weight, you can add a heavy loudspeaker!

Model aircraft do not have that luxury and their loudspeakers must be chosen for high efficiency and low weight.

USING MULTIPLE LOUDSPEAKERS IN SERIES AND/OR PARALLEL

Given the above laws of physics constraining the physical design of speakers, it often makes sense to use more than one loudspeaker so as to share the total power between them.

Wiring of multiple speakers must be done **VERY CAREFULLY** so as not to finish up with too low an impedance and not to wire them up in anti-phase to each other where they will cancel each other out instead of adding to the total sound output!!

Model Sounds Inc. supplies 8 Ohm and 4 Ohm speakers in the 4 inch (100mm) 20 Watt size as well as smaller loudspeakers. The logic here is that on supply voltages of 17 Volts and below, a single 20 Watt speaker can handle all the output power of the sound module so a single 8 Ohm speaker can be used. On voltages above that, say 24 Volts or 6S LiPo packs, the power output is close to 40 Watts so you will need two or more speakers. Since 4 Ohm speakers are more readily available than 16 Ohm ones, you use two 4 Ohm speakers in series to get the desired 8 Ohms total.

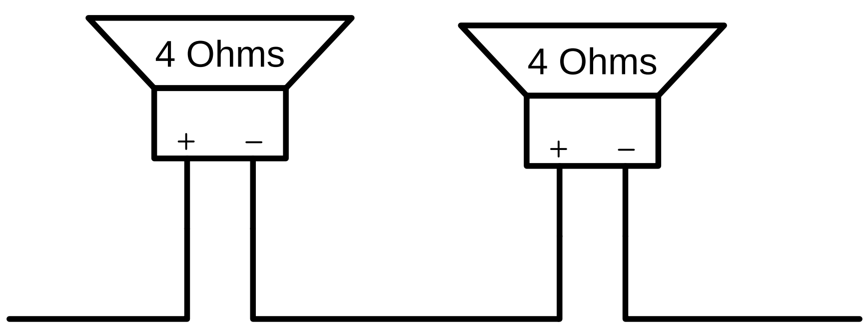
What is Series and Parallel Wiring?

When any two or more electrical devices are wired in series, they are wired with one lead going to the next, daisy chain fashion like the old-fashioned strings of Christmas lights where, if one bulb blew, the whole string went out. Series wiring is used where you want to keep the current the same, but use a higher voltage. This is equivalent to having a higher resistance, or impedance.

Parallel wiring is where each electrical device is wired across the other and both wires from each device go to the power supply. In this way the voltage is the same, but the current is higher. This is equivalent to having a lower resistance or impedance.

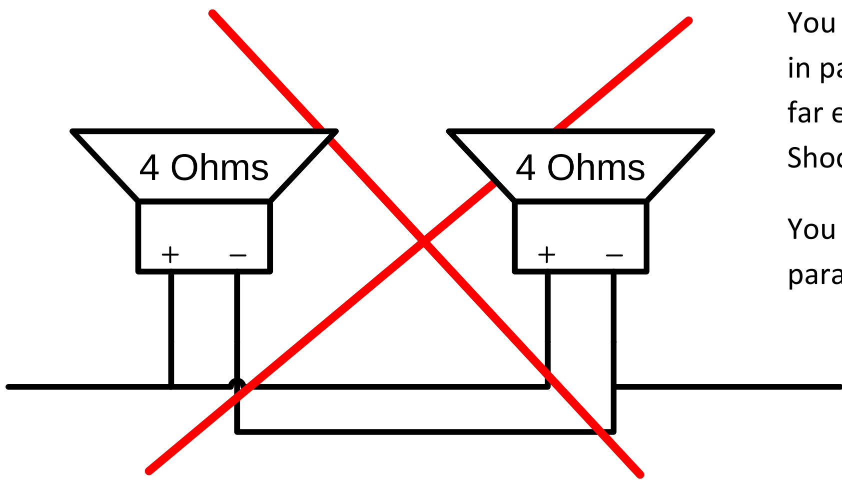
The diagrams below show two speakers in series and in parallel :

Figure 1 - Two 4 Ohm Loudspeakers in Series



Two 4 Ohms speakers in series – 8 Ohms total

Figure 2 - Two 4 Ohm Speakers in Parallel



Two 4 Ohms speakers in parallel – 2 Ohms total

You can see that the two 4 Ohm Speakers in parallel makes a total of 2 Ohms which far exceeds the drive capability of the ShockWave series sound modules.

You would need two 16 Ohm speakers in parallel to get a total of 8 Ohms.

My Speakers Don't Have +/- Markings On Them

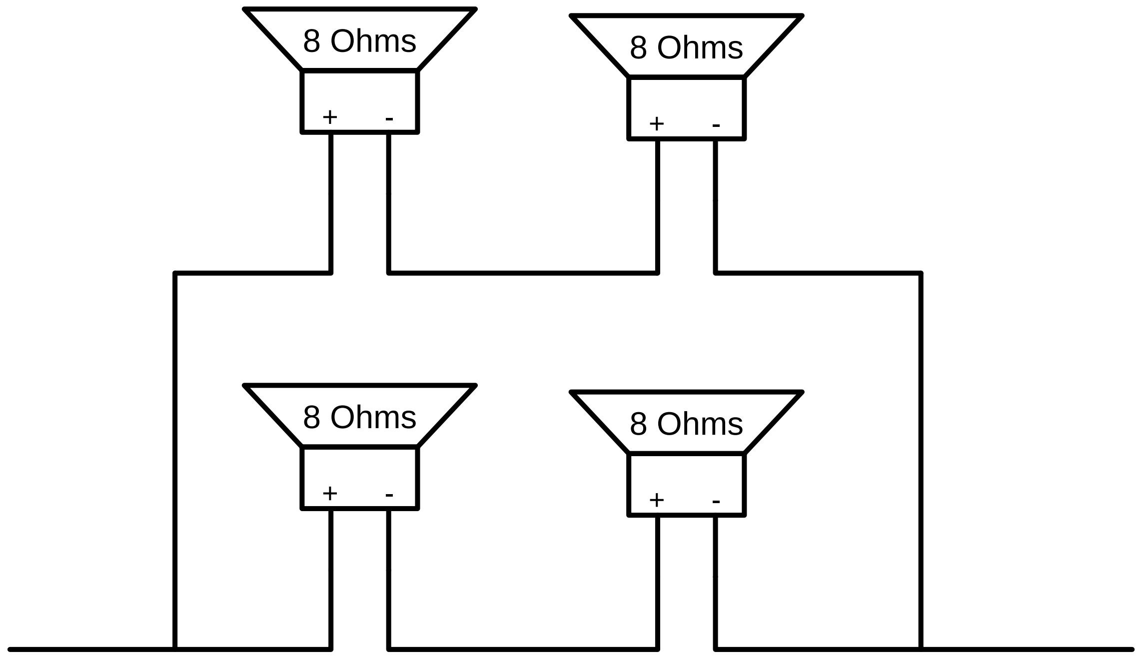
The +/- markings above are shown to illustrate that speakers are polarized. Many speakers don't have actual +/- markings on their terminals. Instead the terminals are usually of different shapes and/or sizes. The same principle applies, for series wiring the large terminal of one goes to the small terminal of the other. For parallel wiring each terminal goes to the same type of terminal on the other.

If you reverse the connections to one of the speakers in either of the above diagrams, the impedance will remain the same, but they will operate in anti-phase or in opposition to each other and will try to cancel each other out!!

Large Arrays of Speakers

To get very large power handling capacity, it is possible to use several smaller loudspeakers than one very large loudspeaker. This is also sometimes easier to install in a model. This is when you need both series and parallel wiring at the same time.

Figure 3 - Series/Parallel Wiring to Get High Power Handling Capacity



Four 8 Ohm speakers in series/parallel – 8 Ohms total

In such a configuration it is **DOUBLY IMPORTANT** to make sure that correct polarities are observed throughout the array.