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

Loudspeaker and Audio Amplifier Ratings, Sound Pressure Level and their often Misunderstood Relationships

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Date: September, 2013

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Introduction

Loudspeaker manufacturers sometimes make misleading and even outrageous claims about how much power their loudspeakers can handle or how loud they sound, i.e. how much Sound Pressure Level (**SPL**) they can deliver. Similarly audio amplifier manufacturers also often make misleading claims about how much electrical power their amplifiers can deliver.

This article hopes to debunk many of the misconceptions and misunderstandings about this area of marketing one-upmanship and clarifies how to interpret the manufacturer's claims.

Specific references are made to assist R/C modellers understand the limitations of loudspeakers used in their models.

What is Power?

In electrical engineering and many other areas of science, the unit of power is the Watt – named after James Watt, the 18th century Scottish inventor.

In electrical engineering, power, i.e. 1 Watt = 1Volt x 1Ampere so the higher the current and/or the voltage, the higher the power produced (or consumed). This is represented by

P = V x I where V is voltage and I is current (equation 1).

Electrical resistance is a measure of how much a wire, or a circuit element, "resists" the flow of electricity - hence "resistance and resistor". That is, the higher the resistance, the less electric current flows through it for any given voltage across it.

Ohm's law states that 1 Volt = 1 Ampere (Amp.) x 1 Ohm. This means that 1 Volt of electrical "pressure", or "voltage", is required to force 1 Amp. of current through a resistance of 1 Ohm.
This is represented by **V = I x R** where I is current and R is resistance

If we combine these two equations we can see that power

P in Watts = V^2 / R (equation 2) or

I^2 x R (equation 3).

Resistance is a measure of resistance to the flow of a steady current flowing in one direction i.e. DC (Direct Current). In the audio world, sound waves and electrical audio signals are constantly changing, i.e. AC (Alternating Current) and the correct term to use is called "impedance" – i.e. a loudspeaker tries to "impede" the AC signals applied to it. Impedance is not the same as resistance, but has resistance as a component of it. It is beyond the scope of this article to fully explain what impedance is, but just accept that from now on we will be using impedance rather than resistance as it applies to loudspeakers and amplifiers. The international symbol for impedance is Z, rather than R, but the above equations still hold i.e. **P = V^2 / Z**.

When an AC current is applied to a circuit, since the voltage and current are changing all the time, the instantaneous power at any instant in time in the circuit is also continuously changing. This is not terribly helpful to us, so we use what is called the "Root Mean Square" or "**RMS**" values of the voltage and current. Again, we will not go into what that means but it is a type of averaging process over time. If the voltage and current are changing with a simple pure sine waveform, the **RMS** value is **1 / √2** of the peak value or **0.707**. Therefore when this is applied to equation 2, above, we get

$\mathbf{P = Vp^2 / (2 \times R)}$ where **Vp** is the peak value (equation 4).

Another useful concept is the "peak-peak" value of voltage which relates easily to the available output voltage swing from audio power amplifiers. Again, for a simple sine wave, the peak-peak value is twice the peak value, so now

$\mathbf{P = Vp\text{-}p^2)/ (8 \times R)}$ where **Vp-p** is the peak-peak value (equation 5).

Loudspeaker Impedance

Where does loudspeaker impedance come from? The vast majority of loudspeakers use a cone of paper, plastic, or metals such as titanium, attached to a "voice coil" which is suspended in a powerful magnetic field produced by a strong permanent magnet. The "voice coil" is literally a coil of wire wound around, and attached to, a cylinder which is then attached to the cone. When an electric current is applied to the two ends of the coil, it generates its own magnetic field which either opposes, or attracts, the permanent magnetic field. Thus the voice coil, the cylinder it is wound on, and hence the cone, moves in and out like a small high speed linear motor. The motion of the cone acts like a piston and pressurizes and depressurizes the air around it. It is these air pressure waves that we hear as sound.

The voice coil has its own resistance due to the wire it is made of. But also, since the cone has to move air out of its way, the air itself impedes the motion of the cone and this is reflected back into the voice coil as an electrical impedance. Furthermore, the total electrical impedance of the loudspeaker varies with the frequency of the applied signal. Thus, when we say a loudspeaker has an impedance of "8 Ohms" it actually only has that impedance at a single frequency. Therefore loudspeaker manufacturers specify a conservative estimate of the average impedance that the loudspeaker will present while playing typical music. This is called the "nominal impedance".

Loudspeaker Power Ratings and Efficiency

Loudspeaker efficiency is defined as the sound power output divided by the electrical power input. Most loudspeakers are very inefficient - only about 1% of the electrical energy sent by an audio amplifier to a home loudspeaker is converted to sound power. The main reason for this low efficiency is the difficulty of achieving proper impedance matching between the acoustic impedance of the loudspeaker and that of the air into which it is radiating.

So where does the other 99% of the input energy go? It is converted to heat, mostly in the voice coil and magnet assembly. If more power is applied than the speaker is capable of handling then the coil may literally burn out, or it may become detached from its cylinder or the cone may be destroyed. This is a one way trip – even if the power is then reduced, the speaker has already been destoyed.

Larger loudspeaker enclosures help to achieve better acoustic impedance matching between the speaker (also called a "driver") and the outside air and are thus more efficient. Various internal structures such as horns, vents, and complicated acoustic paths can be built in to increase their efficiency and improve their frequency response. For example, large loudspeakers used in rock concerts, stadium public address or marine hailing may have efficiencies as high as 10 – 20%.

A small loudspeaker used in an R/C model has a lower efficiency than 1% because of its small or non-existant enclosure. Also there is the problem of the rear sound pressure wave emanating from the back of the cone reflecting off nearby surfaces and destructively interfering with the forward sound pressure wave.

If a loudspeaker is mounted in a very large board (i.e. an infinite baffle), then the rear sound waves can never reach the front sound waves so the effciency goes up and the frequency response is improved. Since an infinite baffle is not practical, the next best thing is to enclose the speaker in a very rigid, airtight box. The enclosure must be very rigid, otherwise the sound pressure inside will vibrate all the walls of the box and then they become sound radiators themselves. Unfortunately rigidity comes at a price – very thick walls are very heavy, and a heavy enclosure is impractical in R/C airplanes.

It is not possible to combine high efficiency (especially at low frequencies) with compact enclosure size and good low frequency response. One can choose only two of the three parameters when designing a speaker system. So, for example, if extended low-frequency performance and small box size are important, one must accept low efficiency. Or, more typically for R/C models, if small size and high efficiency are important, the low frequency response is poor.

As a marketing ploy, loudspeaker manufacturers often quote loudspeaker power handling capacity as "peak" or "music power". This is always much higher than the true **RMS** power handling capacity. Because music is highly variable, the highest music peaks are much higher than the **RMS** value and can be sustained by the loudspeaker without damage only because of the relatively short durations of the music peaks. The short duration of the peaks does not allow the heat to build up to the destructive level before the peak starts to go down again.

These "music" or "peak" power ratings are misleading. The loudspeaker cannot be driven at that power with a continuous signal. In R/C models, engine sounds are very repetitive and while they are not simple sine waves, they do not have the same peaky nature that music does. Thus in R/C models that play engine sounds at high volume, the loudspeaker must be chosen such that its **RMS power rating** is at or above the maximum power output available from the power amplifier or sound module.

Some customers ask us if we have a 4inch speaker that is rated at 30 or 50Watts. This is physically impossible whilst maintaining acceptable magnet size and weight for use in R/C models. Yes, there are some 4 inch speakers with that power rating, but they are intended for automobile use where weight is not an important factor and they have **VERY** large and **VERY** heavy magnets on them. This is why we do not offer them for sale for use with our sound modules. Even going to a 5 inch speaker will not offer a substantially greater power rating. Our own 5 inch speaker is rated at 30 Watts continuous.

The limitation with any loudspeaker is the size of the voice coil and magnet, since it is those components which serve as the heatsink for the heat generated in the voice coil. If you want a higher power rating, you have to have a larger coil and magnet – thus the weight goes up.

We feel that the 4 inch 20 Watt speaker that we offer is a very good compromise between size, weight, power rating, frequency response and sensitivity – it has a sensitivity of 90dbA (1W/1m), can handle 20Watts continuously, yet weighs only 176 grams (6.2oz).

Sound Pressure Levels and Loudspeaker Sensitivity

Sound Pressure Level (SPL) is measured in decibels and is a measure of the actual air pressure of a sound. It could also be measured in Pascals or even lbs/sq. inch. These latter units help you to understand that sound really is air pressure.

The **decibel** (**dB**) is a logarithmic unit of measurement that expresses the magnitude of a physical quantity (usually power or intensity) relative to a specified reference level. Since it expresses a ratio of two quantities with the same unit, it is a dimensionless unit. A decibel is one tenth of a **Bel**, which is seldom used. A significant point to note is that, because it is a logarithmic scale and uses a base of 10, a **3dB** increase in **SPL** represents a **doubling** of **SPL**, a **10dB** increase is **10 times**, a **20dB** increase is **100 times** etc. This applies to **SPL** which is related to sound **power**.

Because power is proportional to voltage squared, dBs as used for **voltage ratio**s have to be doubled – i.e a **6dB** increase in voltage is **double**, **20dB is 10 times**, **40dB is 100 times** etc.

For **SPL**, the reference level is the threshold of human hearing, so 0dB is the **SPL** at which humans can just barely hear.

The human hearing system is very complex – perceived loudness varies with frequency and the human frequency response also varies with sound pressure level. Because of this it is not a simple matter to relate actual **SPL** to perceived loudness. Therefore a weighting scale is used to more accurately represent perceived loudness by giving more weight to sounds at certain frequencies. Various weighting factors are used i.e. A, B, C, D etc. The A weighting factor is most commonly used for **SPL**, and then the units are called **dBA**.

To give you an idea of what various **SPL** levels sound like we have included the table below.

Source of sound	**Sound Pressure Level**
Shockwave	>194 dB
Krakatoa explosion at 100 miles (160 km) in air	180 dB
.30-06 rifle being fired 1 m to shooter's side	171dB (peak)

Jet engine at 30 m	150dB
Threshold of pain	130dB
Hearing damage -instantaneous	120dB
Jet engine at 100m	110 – 140dB
Jack Hammer at 1m	100dB
Traffic on major road at 10m	80 – 90dB
Hearing damage - due to long term exposure	78dB
Passenger car at 10 m	70 – 80dB
Normal talking at 1 m	40 – 60dB
Very calm room	20 – 30dB
Leaves rusting or calm breathing	10dB
Threshold of human hearing	0dB

Loudspeaker manufacturers attempt to give you an idea of how "loud" their speaker is by quoting a sensitivity value such as **90 dBA (1W/1m).** What this means is that, if the speaker is mounted in a very large, or "infinite", baffle and fed with **1Watt** of power, it will produce an **SPL** of **90dBA** at a distance of 1 metre on its main axis.

The above sensitivity is always best case, so if the observer is "off axis", or is further away than 1m, or the speaker is in an inefficient enclosure, or none at all, the **SPL** will be less.

Loudspeaker efficency and power ratings were touched on earlier. A speaker that is **3dB** more sensitive than another will produce double the **SPL** (or be 3 dB louder) for the same power input. I.E. a 20Watt driver rated at **92dBA (1W/1m)** sensitivity will output twice as much acoustic power (**SPL**) as a 40Watt driver rated at **89dBA (1W/1m)** when both are driven with 20Watts of input power. Or another way of saying the same thing is that the first speaker will be just as loud as the second speaker with only half the input power. So loudspeaker sensitivity is an all important factor in choosing a loudspeaker for R/C model use. Using surplus loudspeakers is not recommended as you have no idea what their specifications are.

Audio Power Amplifier Ratings

Audio power amplifier manufacturers (including integrated circuit or I.C. amplifiers) will usually always claim their products can deliver the maximum possible achievable power under the most ideal conditions.
These conditions are :

1. The amplifier is operating at its maximum possible supply voltage – since power is proportional to voltage squared. The available output voltage swing closely tracks the supply voltage, but is always less than the supply voltage in a "single ended" mode.

2. The amplifier is driving its lowest possible loudspeaker impedance – since power is inversely proportional to the driven load impedance, the lowest impedance gives the highest power.

3. The amplifier is driven to usually 10% THD (Total Harmonic Distortion).
   This is a very high level. Hi-fidelity amplifiers usually operate at less than 0.1% THD.

If any of these factors are not met, the available output power drops – sometimes quite dramatically.

There is an amplifier configuration called “Bridge Tied Load” (BTL) which will give twice the available peak-peak voltage swing of a similar single ended amplifier. This is essentially two amplifiers operating in anti-phase to each other, so when the first output voltage is rising, the second output is falling and vice-versa. Twice the voltage swing means four times the available output power – **BUT** also means four times the internal power dissipation which means it must be mounted on a much larger heatsink to keep it within acceptable temperature limits.

Amplifier efficiency is a very important consideration. In a similar manner to loudspeaker efficiency, amplifier efficiency is the ratio of the output power it can send to the loudspeaker to the electrical input power it takes from the power supply.

In audio amplifiers of the kind used in R/C model sound systems, there are two modes of operation – Class AB and Class D.

Class AB amplifiers are a semi-linear amplifier where the amplifier outputs a voltage that bears a linear relationship to its input voltage. This kind of amplifier is usually quite simple and inexpensive, but is quite inefficient – about 60-65% maximum. This means that if an amplifier outputs 60Watts, it is actually consuming 100Watts of power from the power supply - a battery in an R/C model. The other 40Watts is lost as heat in the amplifier and this heat has to be carried away using a heatsink or fan, otherwise the amplifier will overheat and self-destruct.

Class D amplifiers use a switching mode of operation called Pulse Width Modulation (PWM). The output transistors are switched on and off rapidly at a very high frequency well above human hearing (typically 250KHz). The amount of time they are on or off varies with the audio input waveform and the average value of these pulses represents the amplified audio output. These amplifiers usually have a high current output filter to drive the loudspeaker. Contrary to some beliefs these filters are not used to recover the audio content from the pulse stream – the loudspeaker and the human ear combine to do that very effectively. Whilst the filter does contribute to audio waveform recovery, it’s main purpose is to remove, or reduce, the high frequency currents travelling in the speaker wires so that they do not radiate significant radio interference.

Conceptually, Class D amplifiers are more complex, but in the type of sound modules used in R/C models, they are a single integrated circuit chip. Because the output is operating in a switched mode these amplifiers are very efficient – sometimes 85 – 90%. In the case of our 60Watts example, above, if the efficiency is 90%, the total power consumption is only 67Watts, not the 100Watts of the Class AB. More importantly, the internal power dissipation is only 7Watts compared to 40Watts. This amount of heat can be carried away with a much smaller heatsink, and sometimes, with proper board design, no heatsink is required at all.

The Class D amplifier is much more appropriate for R/C models as it can be made much smaller and dissipates far less heat than the traditional Class AB type. All the R/C sound effects modules made and sold by our company have used Class D amplifiers. We have hundreds of our sound modules successfully installed in model airplanes, model boats and model tanks and there has never been any problem with them causing unreliable radio operation.

Now back to amplifier ratings and manufacturers claims. Let us take as an example a commonly available “2 x 40Watts” per channel amplifier. It’s supply voltage range is 6 – 18Volts.

However, this 40Watts is available only when it is operated at its maximum voltage, which is 18Volts. If the voltage is reduced to say 3S LiPos (11.1V), the maximum output power is reduced to approximately 15Watts per channel. It’s that $\mathbf{P = V^2 / Z}$ equation coming into play again.

Now if we dig deeper into the specifications, we find that it can only deliver its maximum power when driving a 2 Ohm load. Most easily available loudspeakers have an 8 Ohm impedance. Some are available in a 4 Ohm impedance, but none are available in a 2Ohm impedance unless they are custom made. To get 2Ohms using readily available speakers, one would have to wire two 4Ohm speakers in parallel – for **EACH** channel. That is only possible in very large models. If the speaker was 8 Ohms, then that 15Watts on 3S LiPos would reduce to **3.75Watts!!**

This example is simply chosen to emphasize that it is definitely **BUYER BEWARE** when taking amplifier specifications on face value without further investigation!!

The other issue with amplifier specifications is that of internal power dissipation and removing that heat.
Often times, a large heatsink is required to keep the amplifier from self-destructing when operating at its maximum, or even sometimes, much lower, output power. And usually, the size of the heatsink required is very vague in the specifications, if mentioned at all.

If the heatsink is not adequate, the amplifier may have a shortened lifetime, as was the case with the notoriously unreliable sound modules that were sold by JJC in the U.K. until 2008 when they went out of business.

Acknowledgements

We wish to acknowledge that some material came fromWikipedia.org.

Most of the material came from the author’s own knowledge and experience with audio systems and loudspeakers over his 50 plus years as an electronic engineer.

