COGITO ERGO BOOM

JL AUDIO

SCHOOL OF SOUND

A Short Course in Audio

Introduction

In the car audio business, we don't just sell products and install them. We are selling something far more interesting; the enjoyment of music. In order for music to become an experience it has to transcend the nuts and bolts and make the listener forget that they are listening to equipment. This level of performance doesn't just happen. It has to be designed with knowledge and care.

Sometimes it is easy to forget what our customers are really looking for and how closely it fits in with our goals as salespeople and installers.

Customers want:
1) Performance that meets/exceeds expectations
2) Reliability
3) Confidence that they have purchased the right product for their needs
4) Good service (advice, installation quality, efficient problem resolution)
5) Value for their money... which is directly related to 1-4

Retailers want:
1) Profitability
2) Business Growth

The retailer only achieves profitability and business growth when customers consistently get what they want. Broken products cost everyone time and money and make customers mad, which reduces the likelihood of referrals or repeat purchases. Systems that don't sound good cost you future business, too... you get the picture. To be truly successful, we must strive to make customers happy via great performing, reliable systems.

In this training, we will cover several important topics which are fundamental to making good system design choices. This training will help cover the following topics in detail:

1) The fundamentals of electricity, including Ohm's Law
2) The fundamentals of acoustics: decibels, octaves, SPL, etc.
3) The fundamentals of speaker power handling
4) The fundamentals of charging systems
5) The fundamentals of power distribution in a system
6) The fundamentals of system level setting

These may sound like pretty "dry" topics, but we'll attempt to illustrate their application in a manner that is highly relevant to our everyday business of recommending, selling and installing audio products. We will also discuss something throughout that is rarely talked about in mobile or marine audio trainings: the music and its role in making good system design choices.

This information will allow salespeople to confidently make good choices for different situations and explain their recommendations to their customers. Installers will benefit from the acoustic, electrical and system tuning information as well.

Module 1: Electrical Basics

A solid understanding of these fundamentals is absolutely necessary in order to understand audio in general. We will start by covering the fundamentals of electrical theory from basic definitions of current, voltage, resistance and power to Ohm's Law, electromagnetism and the calculation of multiple resistances in series, parallel and series-parallel circuits. Much of what is explained here is necessary to the understanding of musical signals, automotive charging systems, speaker behavior, amplifier technology and much more.

Let's start with current.

Current is simply the movement of electrons through a conductor or a circuit. It can also be described as the flow of charge in a circuit. The scientific symbol for current is the letter "I" (not the letter "C"), however on your meter you are likely to see a capital letter "A". This is because current is measured in SI units called "Amperes", commonly called "amps", and measured with an instrument called an ammeter.

There are two types of electrical current:

Direct current (DC) flows from the negative polarity of a circuit to the positive polarity (see the diagram of the battery below). (Some books will tell you that it flows in the opposite direction, which is not necessarily incorrect). Direct current is typical of battery powered circuits, like a flashlight or a transistor radio. The battery essentially provides a supply of electrons that flow, making things happen to anything connected in between its terminals. A water hose analogy helps us understand direct current. Imagine a garden hose connected to a water supply (see the diagram below). Direct current in a wire is like water flowing in this hose.

For direct current to happen, the circuit must contain the following elements:

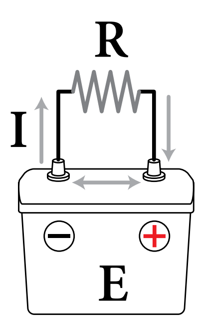
1) A source or supply of voltage (a battery, for example).
2) A load which uses the voltage (a car amplifier, for example).
3) A complete path of connecting wires.

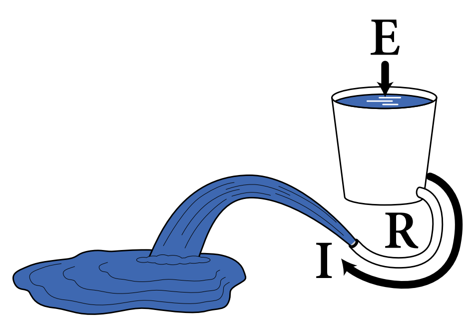
Alternating current (AC) occurs when the charge flows back-and-forth in a wire. We call this reversal of direction a change in polarity. The rate of change in the polarity (alternation) of the charge is referred to as the frequency and is measured in cycles per second or Hertz (Hz). Household AC current in the U.S. cycles polarity at 60 Hz (60 times per second). Another example of an alternating current is an audio signal between an amplifier and a speaker.

Voltage is the electrical pressure that makes the current possible and is measured in volts. The more technical definition is "the electrical potential difference between two points". The instrument used to measure it is called a voltmeter and the scientific symbol for it is the letter "E" (not "V"). However, your meter is likely to show a capital "V". This may be the most confusing part of electricity.

Going back to the water hose analogy, DC voltage is very much like the water pressure feeding the hose. A greater voltage can create more movement of electrons just like an increase in water pressure can create greater movement of water, given a particular hose.

Voltage by itself does nothing, until the charge is given a path to travel. It is simply the potential force behind electricity.





Resistance is the opposition offered by a conductor or circuit to charge flow (current). The unit for measuring resistance is the Ohm and the instrument to measure it is called an ohmmeter. The scientific symbol for resistance is the letter "R" (at least one of them makes sense). To continue the trend, your meter will most likely show you the "Ω" symbol instead.

This is similar to the way that the hose in our DC fluid analogy imposes some friction on the water flow, limiting its flow. By adding an adjustable nozzle to the end of the hose, we can further add friction and restrict flow. This increase in friction can be described as adding a restriction to the flow of water. The electrical equivalent of this is called resistance.

Maximum resistance is achieved in an open circuit, one which does not offer a direct path for electrons to flow at all (think of a closed nozzle on the hose). Minimum resistance is present in a short circuit which offers a direct path for electrons to flow (think of the water tank rupturing). This is typically not good because excessive current will overdrive the electron flow and burn up the conductive material. In between an open circuit and a short circuit is where useful things happen with electricity. It's all about controlling current, via resistance, to do work. All conductors exhibit some resistance and anything that works with electricity uses resistance to harness it.

An inevitable by-product of resistance is heat. In other words, the energy lost while going across the resistor isn't really lost, but transformed into heat energy (much like the brake pads on your car employ friction to transform mechanical energy into heat in order to stop the car).

Ohm's Law: The interaction of voltage, current and resistance is well understood and encapsulated in a formula called Ohm's Law. This formula is the key to understanding the behavior of electricity. Ohm's Law states that the voltage (**E**) in a circuit is equal to the current (**I**) in the circuit multiplied by the resistance (**R**) in the circuit. You can use simple algebra to reword the equation to allow you to find any of the three parameters by knowing the other two. This is extremely useful in analyzing any electronic device or audio signal.

To find the equations you need, place a thumb over the variable you wish to find. The remaining two letters form the desired equation as shown below.

Ohm's Law states:

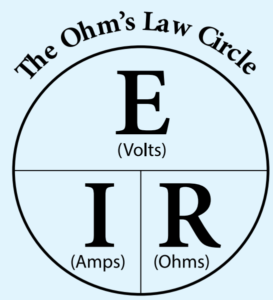
Voltage (E) = Current (I) x Resistance (R)

Using simple algebra, we can twist the basic formula around to solve for current or resistance as follows:

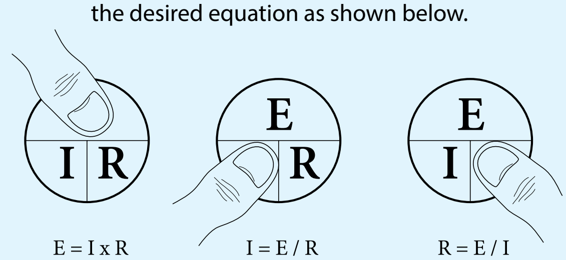
Current (I) = Voltage (E) / Resistance (R)

Resistance (R) = Voltage (E) / Current (I)

A simple and easy tool to help remember and use this law is the *"Ohm's Law Circle"*.



To find the equations you need, place a thumb over the variable you wish to find. The remaining two letters form the desired equation as shown below.



Examples:

Example #1: If we know that we have 3 amps of current (I) through a resistance (R) of 4 ohms. How many volts (E) do we have?

We'll use E = I * R for this one:

E = ??
I = 3 Amps
R = 4 Ohms

E = I * R
E = 3 * 4
E = 12 Volts

Example #2: If we know that we have 12 volts of potential and a resistance of 4 ohms. How many amperes do we have?

We'll use I = E / R for this one:

E = 12 Volts
R = 4 Ohms
I = ?? Amps

I = E / R
I = 12 / 4
I = 3 Amperes (amps)

Example #3: If we know that we have 12 volts of potential in a circuit and 3 amperes of current, we can solve for resistance as follows:

E = 12 Volts
I = 3 Amps
R = ?? Ohms

R = E / I
R = 12 / 3
R = 4 Ohms

We all use this term "**power**" every day when discussing audio products and we all know it is measured in watts. But what is power exactly? In basic terms, power is the "rate of doing work". For example, let's say you need to push a broken-down car one mile; that's the "work" and it represents a certain amount of energy that will be required. If we push it by ourselves as hard as we can (one man-power), it will take a long time. If we get two guys to push as hard as they can (two man-power), we can do it faster. If we use our cell phones to call a 300 HP tow- truck... you get the idea. In all three cases, the work eventually gets done and the total energy applied to do the work is the same, but having more power gets it done faster.

A watt is defined as "one joule per second". A joule is a measure of work and a watt is a measure of the rate of doing that work. This is much like a mile is a unit of distance and a "mile-per-hour" is a measure of the "rate of traveling a distance".

Fortunately, Ohm's Law helps us calculate power in watts (no joules needed) using the following basic formulas:

Power (P) = Current (I) x Voltage (E)

This is easy as **P I E**, get it?

And we can easily solve for voltage or current if we know the other two:

Voltage (E) = Power (P) / Current (I)

Current (I) = Power (P) / Voltage (E)

Here are two more very handy formulas for power:

$P = E^2 / R$
Power = voltage squared, divided by resistance

$P = I^2 \times R$
Power = current squared, times resistance

Let's practice this whole Ohm's Law thing with a few more examples:

Example 1: How much voltage does it take to cause 20 amps of current through a resistance of 100 ohms?

We'll use E = I * R to solve this.

E = ?? Volts
I = 20 Amps
R = 100 Ohms

E = I * R
E = 20 * 100
E = 2,000 Volts

Example 2: With a 6 volt supply, what is the resistance associated with 3 amps of current?

We'll use R = E / I for this one:

R = ?? Ohms
E = 6 Volts
I = 3 Amps

R = E / I
R = 6 / 3
R = 2 Ohms

Example 3: How much power is drawn by a load with 100 amps through it and 100 volts across it?

We'll use P = I * E for this problem.

P = ?? Watts
E = 100 Volts
I = 100 Amperes (Amps)

P = E * I
P = 100 * 100
P = 100 x 100 = 10,000 watts (10 kilowatts)

Example 4: What is the minimum power rating for a 20 ohm resistor if you want to apply 12 volts across its terminals?

We will use $P = E^2 / R$:

P = ?? Watts
E = 12 Volts
R = 20 Ohms

$P = E^2 / R$
$P = 12^2 / 20$
P = 144 / 20
P = 7.2 Watts

To be safe, we'll recommend a 10 watt resistor.

Example 5: The maximum unclipped output voltage of an amplifier designed to operate into 4 ohms is 27 volts. How many watts will it produce into a 4 ohm load, and how many amps of current will be present across the 4 ohm load?

We'll use $P = E^2 / R$ to figure out the power:

P = ?? Watts
E = 27 Volts
R = 4 Ohms

$P = E^2 / R$
$P = 27^2 / 4$
P = 729 / 4
P = 182.25 Watts

Now, we'll use I = E / R to figure out the current:

I = ?? Amps
E = 27 Volts
R = 4 Ohms

I = E / R
I = 27 / 4
I = 6.75 Amperes (amps)

So, to deliver 183 watts of power across a 4-ohm load requires 27 volts and 6.75 amps of current across the load. We figured the whole enchilada out just from knowing the resistance of the load and the output voltage of the amplifier.

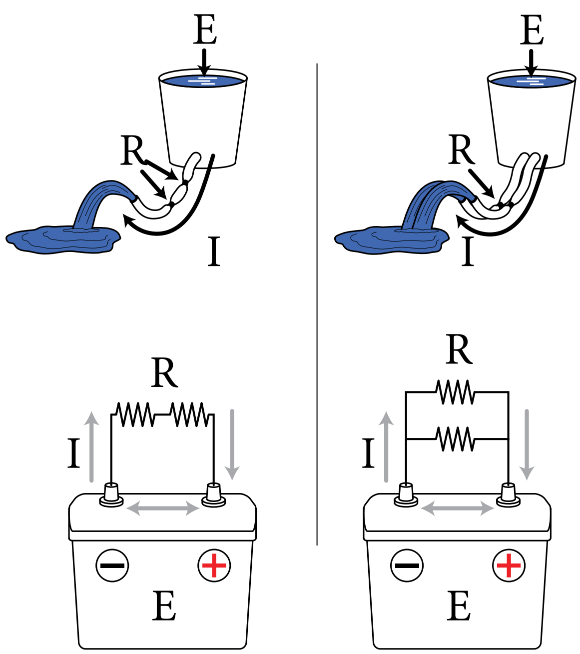
Basic Circuits

Most circuits contain multiple resistive elements which can either exist in series, parallel or both configurations.

In a parallel circuit, resistances are connected so as to allow multiple current paths.

In a series circuit, resistances are connected in a straight line (like a chain) and allow only one current path.

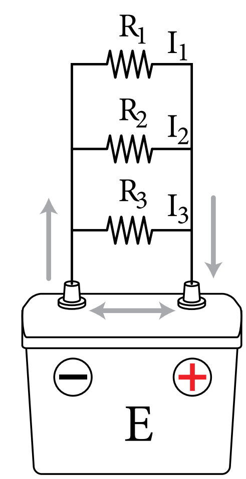
In the diagram below, the image on the left compares two series resistances to the flow of water from the bucket. The image on the right compares two parallel resistances to the flow of water from the bucket.



Parallel circuits have the following properties:

- Voltage remains constant throughout the circuit because it has individual paths to follow.
- There can be many different currents as each "leg" has the same voltage but can have different resistances. Current can be identical on all legs only if the resistance of each leg is the same. For example, if you had one hose with a little restriction and another with a lot of restriction coming out of the water tank, the flow would be greater in the one with less restriction.
- The total current in a parallel circuit is equal to the sum of all the individual currents on each leg of the circuit ($I_{total} = I_1 + I_2 + I_3$, etc.).
- The total resistance of a parallel circuit is calculated as follows:

$$R_{total} = 1 / (1/R_1 + 1/R_2 + 1/R_3, \text{etc.})$$



That last formula might look a bit scary, but it's actually not that bad. Here are some examples to demonstrate the use of the formula.

First, an easy one:

If we have two 4-ohm loads wired in parallel, what is the total resistance? You already know the answer, right? Let's do the math to check ourselves:

$R_1 = 4$
$R_2 = 4$
$R_{total} = ??$

$R_{total} = 1 / (1/R_1 + 1/R_2)$
$R_{total} = 1 / (1/4 + 1/4)$
$R_{total} = 1 / (0.25 + 0.25)$
$R_{total} = 1 / 0.5$
$R_{total} = 2$ ohms

Now for a more complicated one. If we have a 4-ohm resistance on the first leg (R_1), a 2-ohm resistance on the next leg (R_2) and a 2-ohm resistance on a third leg (R_3), we plug it all in as follows:

$R_1 = 4$
$R_2 = 2$
$R_3 = 2$
$R_{total} = ??$

$R_{total} = 1 / (1/R_1 + 1/R_2 + 1/R_3)$
$R_{total} = 1 / (1/4 + 1/2 + 1/2)$
$R_{total} = 1 / (0.25 + 0.5 + 0.5)$
$R_{total} = 1 / 1.25$
$R_{total} = 0.8$ Ohms

That's all there is to it!

Series Circuits have the following properties:

- Current remains constant throughout the circuit. Going back to the water tank analogy, it is logical that at no time can more water flow through one flow restrictor than another.
- There can be many different voltages, as a voltage drop will appear across every resistor. If the resistors are different values, the various voltage drops will be different. If all the resistors are the same value, then the voltage can be the same throughout the circuit.
- The total resistance of a series circuit is equal to the sum of all the individual resistances in the circuit. ($R_{total} = R_1 + R_2 + R_3$, etc.). This is a lot easier to calculate than parallel resistances; just add up the individual resistances and you have your answer.

Let's try an easy example to show this in action:

If we have two 4-ohm loads wired in series:

$R_1 = 4$
$R_2 = 4$
$R_{total} = ??$

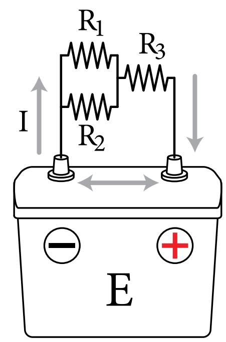
$R_{total} = R_1 + R_2$
$R_{total} = 4 + 4$
$R_{total} = 8$

Essentially, you simply add all of the resistive values to find the total resistance. If you have a 4-ohm resistor, a 2-ohm resistor and another 2-ohm resistor in series, you add 4 + 2 + 2 to get a total of 8 ohms.

Series-Parallel Resistance occurs when both series and parallel resistances are present in a circuit as shown in the diagram below.

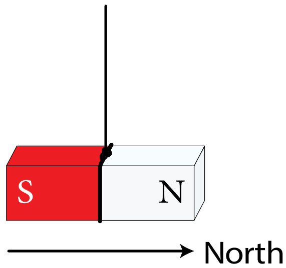
The properties of series circuits and parallel circuits exist in different parts of the overall series-parallel circuit. These can be measured and analyzed by breaking the circuit down into smaller sections and looking at the sections individually.

For example, to calculate the total resistance of a series- parallel circuit, simply calculate each parallel section individually and add it to the series resistance(s). In the drawing below, you would calculate the parallel resistance of "R_1" and "R_2" and then add that result to "R_3" to arrive at the total circuit resistance.



Electromagnetism

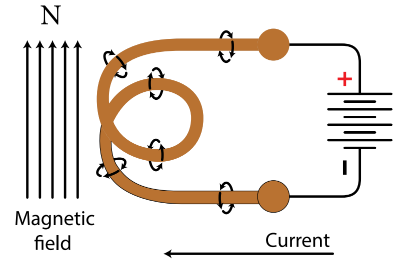
If we suspend a bar magnet from a string so that it can rotate freely, one end will always point towards the north. We call this end of the magnet its north pole.



If we take two magnets and orient them so that the north pole of one is brought close to the south pole of the other, the two will attract each other. If, on the other hand, we attempt to join the north poles of the two magnets or the south poles of the two magnets, we find that they push each other away. This effect is called the "Law of Poles" which quite basically states: "Opposite poles attract each other and like poles repel each other".

Wires carrying current produce the same type of magnetic field that exists around a permanent magnet. The electric current creates a magnetic field around the wire in a process called electromagnetic induction. To observe this phenomenon, you can place a magnetic compass in close proximity to a wire carrying electrical current. The compass needle will turn until it is at a right angle to the wire, showing that there is a magnetic field, at right angles with the conductor.

If we then coil the conducting wire, the total strength of the magnetic field will be greatly magnified compared to a straight and equal length of wire. The direction of the magnetic field is now easily predictable. The positive end of the battery is always connected to the north pole of the coil, regardless of whether the coil is wound clockwise or counter-clockwise. This also means that we can control the polarity of an electromagnet (coil), by controlling the polarity of the voltage being fed into it. If you think of a voice coil in a speaker, you're starting to understand how we can get it to move up and down in reaction to the permanent magnet's field.



Let's make electricity!

Just as a current passing through a wire generates a magnetic field, a magnetic field passing through a wire generates current. This is known as **magnetic** or **electromagnetic** induction. Knowing this, we can generate electricity by moving a magnet in close proximity to a wire.

The magnetic field must be moving in relation to the wire in order for a current to be generated in the wire. In other words, either the magnet, or the wire must be moving, and the faster the wire passes through the field, the more current is generated.

To be clear, according to the physical law of conservation of energy, energy cannot be created or destroyed. And this is a law of physics, not a suggestion, or a guideline. So, the energy we are generating with our wire and magnet has to come from somewhere. In this case, the energy is transformed from mechanical momentum into electrical current via a process called induction. This is how all generators (and alternators) work.

A simple experiment to show the effect of induction is to connect a voltmeter (AC Voltage mode) to the terminals of a loudspeaker sitting on a table. Now, move the cone of the speaker with your hand and observe the voltmeter. You are actually generating electricity using the power of your arm to move the voice coil within the speaker's magnetic gap, which induces current and makes electricity flow.

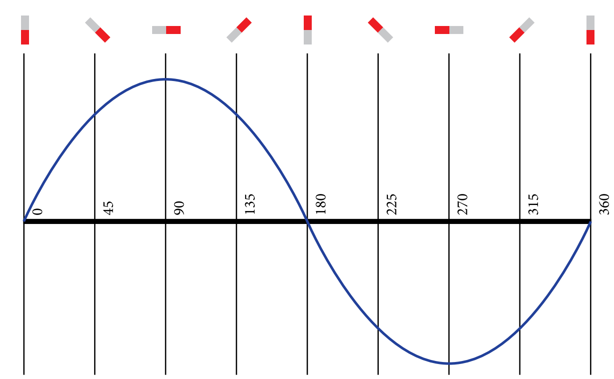
The Basics of Alternating Current

There are a number of ways that electricity can be produced. The two most common ones are chemical (batteries, fuel cells, etc.) and mechanical (generators, alternators, etc.). There is a fundamental difference between the type of electricity produced by a battery and that produced by a generator. A battery produces direct current (DC), which we've learned travels in only one direction. A generator, on the other hand, produces a more complex form of electricity.

Inside a generator, as the wire coil rotates, it first passes the north pole of the magnet, producing an electric current flowing in a given direction. As the coil continues on its circular path, it moves toward the south pole. As it approaches the south pole, the electric current begins to flow in the opposite direction from which it was originally moving. It continues to move in this direction until, once again, it approaches the north pole. We say then that the electrical current is alternating between positive and negative. We call this type of current alternating current (AC).

If we were to plot this swing from positive to negative on a graph and compare it to the time it takes the generator to turn, we would come up with something like the chart below.

" " Represents a rotating coil cutting through a magnetic field.



As the generator is forced to turn by mechanical force, one side of the magnetized coil moves toward the north pole. This end of the wire would become positive. At the same time, the other side of the coil moves toward the south pole. This side of the coil becomes negative. Current begins to flow from the positive to the negative and continues to flow in this direction until it reaches a peak in its cycle. This maximum amount of current flow is reached when the coil is pointing exactly north and south relative to the generator's fixed magnetic field. The signal has now reached its positive peak at 90 degrees of rotation. After it passes this point, the voltage begins to drop, but doesn't reach 0 until once again the coil is positioned directly between the permanent magnets. This is at 180 degrees of rotation.

Now comes the polarity reversal. As the coil continues to turn, the end that was positive now moves toward the south pole of the magnet. Because it is passing by the south pole, this end of the coil swings negative. At the same time, the side of the coil that was negative, is now swinging positive. The direction of current flow within the wire is now switched. The current continues in this direction until it again reaches a (this time negative) peak at 270 degrees of rotation. Finally, as the coil approaches it's original position, it swings positive until current flow again reaches 0. A new cycle now begins.

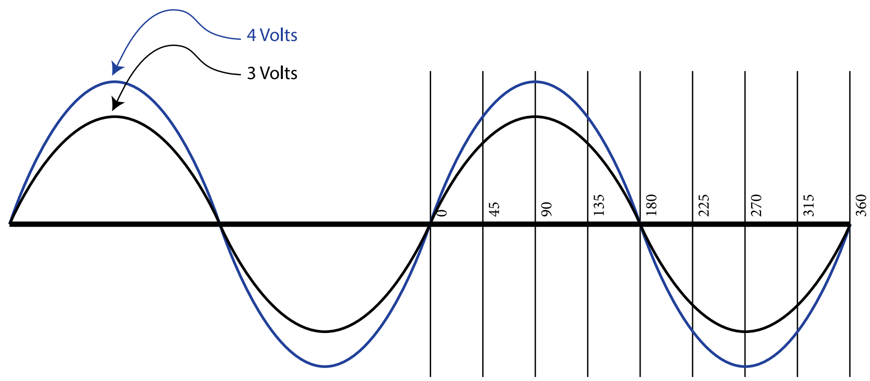
By graphing the current vs. time, we end up with a pattern known as a **sinusoidal wave**, or **sine wave** for short. We say that the sine wave has positive and negative peaks at 90 degrees and 270 degrees respectively.

Here are some things everyone needs to know about sine waves:

- A **cycle** is one complete revolution of a generator, from 0 degrees to 360 degrees.
- A **wavelength** is the physical distance between the beginning of one cycle, and the beginning of the next cycle.
- A **period** is the time it takes to complete one cycle.
- **Frequency** is the number of complete sine wave cycles generated in one second and is measured in cycles per second (cps), periods per second (pps) or more typically, Hertz (Hz).
- The height of the sine wave is called the **amplitude** and is measured in volts. The highest point of any wave is called the **peak amplitude** or **peak voltage**.
- The difference in amplitude between the highest positive voltage, and the highest negative voltage is called the "**peak- to-peak voltage**", which is equal to twice the peak voltage.
- **Phase** is the timing relationship between two or more sine waves.

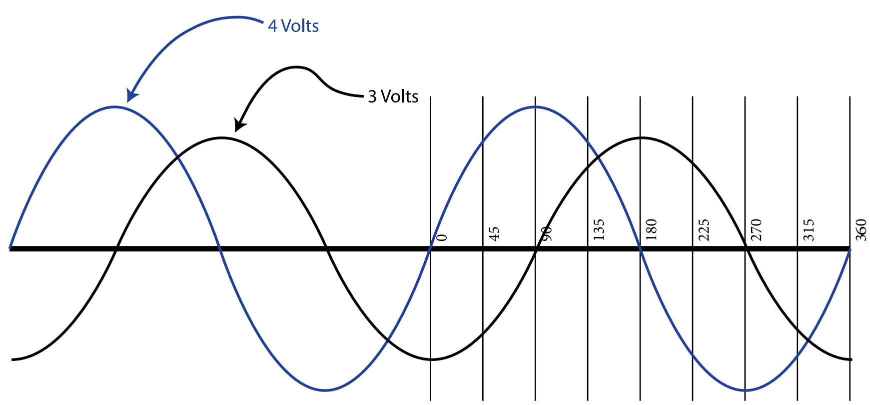
Please Note: Even a "DC generator" or "dynamo" will generate AC first, through the process described above. In these devices, the AC is converted to DC at the output via a commutator, which reverses the polarity of the output every 180 degrees of rotation to create a pulsed DC output. Modern alternators convert AC to DC via a rectifier circuit.

Let's take a closer look at phase. If two generators (a large one and a small one) are connected across a given load in series, and if their armatures begin rotating together at exactly the same time and speed, two different alternating voltages will be produced. In the example below, one is a 4-volt sine wave, and the second is a 3-volt sine wave.



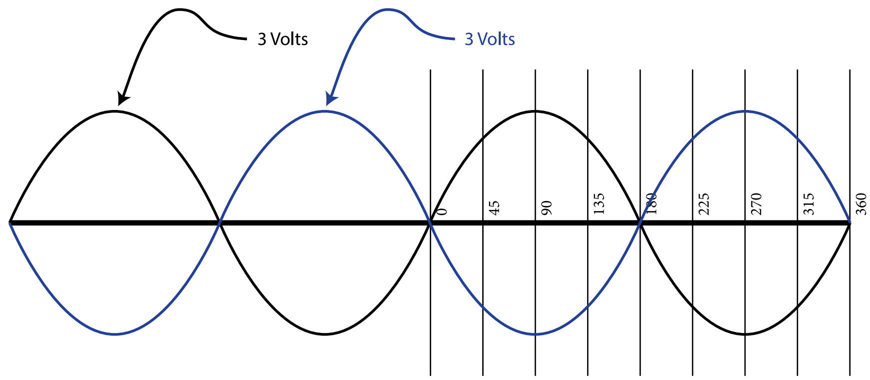
If we examine the picture closely, we find that both sine waves meet up at the 0 degree and 180-degree points. Furthermore, they both peak out at 90 degrees and 270 degrees, respectively. We can therefore say that both waves produced by the two different generators are "in phase" with each other. Whenever two waves are in phase, like these are, the voltage resulting from the two waves will not be the same as either of the two voltages. The resulting voltage will be the sum of the two voltages. In this case, we have 3 and 4 volts being produced by the generators, and the resulting output voltage would be 3+4, or 7 volts. This is because the energy in the two voltages work together and combine to add up to 7 volts. But what happens if the generators are not in phase?

Whenever two waves are combined out of phase, the resultant waveform is not so simple to figure out. Look at the picture below. The 3-volt generator was started later than the 4 volt generator. We say that the 3-volt wave lags behind the 4-volt wave. In this case, the 3-volt wave lags by 90 degrees. Voltages that are out of phase can not be added simply by adding them together, as we do with in phase waves. More complex math is required, which is outside the scope of this training.



3 Volt sine wave begins at 90 point of the 4 Volt sine wave

If two identical voltage sine wave generators are 180 degrees out of phase, their combined output will be zero. That is, they will cancel each other perfectly, much like two woofers connected “out of phase” make no bass. (Technically, the term phase is incorrect here. **Polarity** is the correct term, but we use “phase” here to help illustrate the concept)



One 3 Volt sine wave begins at 180 point of the other 3 Volt sine wave

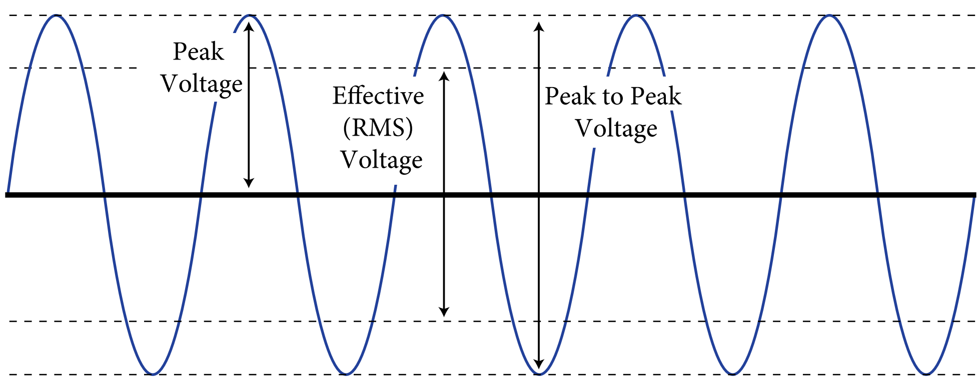
The fundamental differences between AC voltage and DC voltage

DC voltage is straightforward. If it’s 10 volts, it’s 10 volts - period.

Figuring out AC involves more complicated math than DC does. One example of this rears its ugly head when you want to convert an AC voltage level to its DC “equivalent voltage”, or vice versa.

Looking at an AC wave, we actually have 3 different voltages to compare.

- The voltage from the 0 line to the positive peak of the AC curve or “Peak Voltage”.
- The voltage from the top of the positive peak to the bottom of the negative peak, or “peak-to-peak voltage”. For a sine wave, this is equal to two times the peak voltage.
- The “effective voltage. It has been found that it takes a 141 Volt AC wave to do the same amount of work as a 100 Volt DC source. The “effective” value of a 141 Volt AC source then is only 100 Volts. Another term for effective voltage is “RMS” (Root Mean Square).



More on effective (RMS):

A 10 Volt peak AC voltage will not turn a motor as fast as a 10 Volt DC Voltage because a 10 Volt peak AC Voltage is only 10 Volts for an instant, whereas 10 volts DC is 10 volts all the time.

This is why it is often useful to convert AC voltages to effective or RMS voltage. This can be thought of as the "equivalent DC voltage". The following formula can be used for this purpose.

$$E_{eff} = 0.707 \times E_{peak}$$

Should you desire to derive the AC peak voltage from the effective voltage, the following formula can be u sed.

$$E_{peak} = 1.41 \times E_{eff}$$

Remember, E_{peak} equals the peak voltage of an AC signal and E_{eff} equals its effective (RMS) DC equivalent.

Module 2: The Basics of Sound

The scientific definition of sound: Sound is a periodic mechanical disturbance propagated through an elastic medium (like air, for instance).

The simple human definition: Sound is the perception of vibrations stimulating the ear.

A vibrating source (like a loudspeaker) pushes air molecules back and forth, creating areas of compression (high density / pressure) and rarefaction (low density / pressure). It is important to realize that the loudspeaker really doesn't cause the air to travel. It simply causes an alternating pressure wave to move through the air.

The energy of a sound wave travels away from the source through a series of molecule collisions. The higher the initial pressure, the harder the molecules will collide and the farther the wave will travel. The amplitude or volume of a sound wave is the amount of pressure exerted by a sound source to air molecules. *High pressure = high amplitude.*

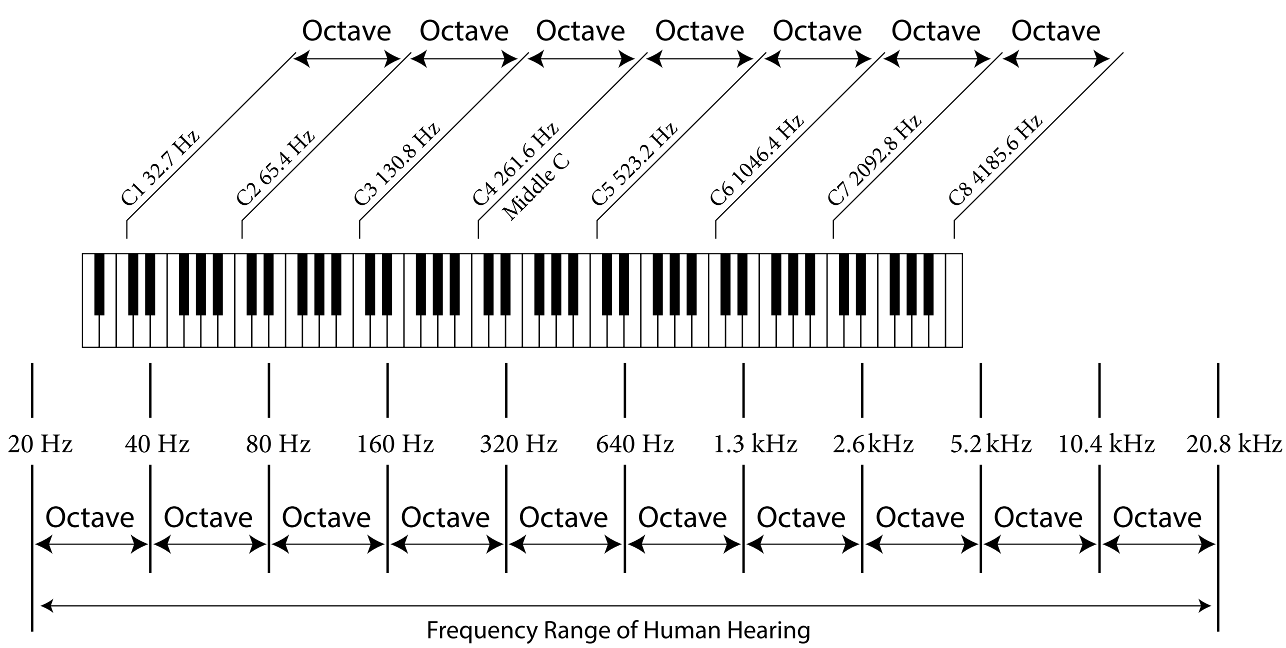
The velocity of a sound wave depends on the temperature of the medium and its elasticity (more elasticity means that molecules will move easily). The speed of sound through air is approximately 343 meters/sec. (1125 feet/sec.). This speed can vary slightly, depending on barometric pressure and temperature. Another way to look at this is that sound travels 1.125 feet or 34.3 cm every 1/1000th of a second (1 millisecond).

The rate of repetition of a sound wave (or any wave) is known as **frequency**. It is expressed in cycles per second, also known as **Hertz** (Hz.). The range of frequencies audible to humans is generally accepted as being 20 Hz to 20,000 Hz (also expressed as 20 kilohertz – 1,000 Hertz is a kilohertz – This can be abbreviated as "20 kHz"). Sound waves with a frequency below 20 Hz are known as **infrasonic** (not to be confused with "**subsonic**"; which means slower than the speed of sound). Frequencies above 20 kHz are considered **ultrasonic** (not to be confused with "**supersonic**"; which means faster than the speed of sound).

Infrasonic and ultrasonic sound waves are considered outside the range of human hearing.

The significance of a single **Hertz** diminishes as frequency rises because our hearing mechanism perceives frequency as a ratio rather than an increment. For this reason, we describe our perception of frequencies in **octaves** and fractions of octaves.

An **octave** is an interval between two frequencies in which the higher one is twice the value (in Hertz) of the lower one. The 20 Hz – 20,000 Hz range is composed of ten octaves. Octaves are not just limited to multiples of 20 Hz. Any frequency range in which the higher frequency is twice the lower frequency is an octave. For example 330 Hz – 660 Hz or 3250 Hz – 6500 Hz. The perceived **tone** of a sound wave is called **pitch**. In music, different pitches are represented by notes (C, D, E, etc.). **Pitch** is directly related to frequency and a musical octave is the same as an acoustic octave... it also represents a doubling of frequency. See the piano frequency range below.



Loudness is our hearing mechanism's perception of the power of a sound. Our hearing mechanism reacts logarithmically to sound both in amplitude and frequency. The ratio of the sound pressure from the lowest limit that (undamaged) ears can hear to the pressure that causes permanent damage from short exposure is more than a million to one. To deal with such a huge range of pressures, logarithmic units, which express ratios rather than increments, are most useful. Decibels are logarithmic units.

Sound pressure is a scientific measure of the power of a sound. It is typically stated and measured in "dB SPL". SPL stands for "sound pressure level".

Sound pressure changes relative to power:

As stated above, the **decibel** (dB) is a logarithmic unit used to describe a ratio. In other words, it expresses a proportional difference between two values. The ratio may be power, or voltage or intensity or several other things.

An increase of +10 dB is equal to 10 times the power (watts). For example, 10 watts is 10 dB higher than 1 watt, 100 watts is 20 dB higher than 1 watt, etc. When related to sound pressure, **an increase of 10 dB is perceived by human hearing as a doubling of loudness**.

Because decibels are relative measures, you can't really ever say that something is "20 dB" without making a reference to what you are comparing it to. It's like saying that a product is "half price" without listing the regular price. We must always have a point of comparison or "reference".

For example, on an equalizer the reference level is "0 dB" which represents the original signal level entering the EQ. The equalizer allows you to boost or cut the signal by a certain number of decibels above and below the original signal level in each of its bands.

Another common example is a digital volume display on a modern head unit or home receiver. Many of them give you a negative decibel figure at any volume below maximum. At maximum volume, the display reads "0 dB" and as you lower the volume, it will read -1, -2, -3... all the way down to -50 or -60. In this case, "0 dB" is full output of the head unit and the volume display tells you how many decibels below full output you have the volume control set.

Those who have studied electronics may have seen the term "dBm", in which the reference is one milliwatt (1 mW). Another decibel-related term is "dBW", in which the reference is one watt (1 W). There always has to be a reference point.

When we talk about sound pressure, we use "decibels SPL" or "dB SPL". The "SPL" suffix explains what we are talking about and that we are referencing the decibels to "0 dB SPL" which is internationally agreed upon as a pressure reading of 20 micropascal, which is not terribly important to remember. Let's just say that it is the absolute quietest sound a human being could ever hear under the best possible conditions. Sound pressure levels in decibels are always referred to this standard.

In autosound competitions we measure sound pressure without a weighting scale (unweighted SPL). This means that the energy at all frequencies is given equal emphasis in the measurement and results in the biggest number. In industrial and environmental noise studies one of two weighting scales, A or C, is almost always used. These readings are listed as "dBA" or "dBC" sound pressure readings, depending on which weighting scale is used. Both weighting scales de-emphasize low and high-frequency sounds, making their readings not very comparable to unweighted readings. This is the cause of much confusion, especially when people wildly claim that a car stereo is just as loud as a 747 at take-off. Chances are that the 747 was measured with A-weighting and you simply can't compare the numbers to unweighted SPL readings.

Let's see just how big these decibels are and what they mean in terms of power:

A 1 dB change in sound pressure level is the smallest difference perceptible by normal human hearing under very controlled conditions, using a pure tone (sine wave) stimulus. A 1 dB change in level is very difficult to hear when listening to dynamic music.

To produce an increase of +1 dB you need to increase power (watts) by a factor of 1.26. So, if you are getting 102 dB SPL from 100 watts and you want 103 dB SPL, you will need 126 watts of power. To produce a decrease of –1 dB you need to divide the reference power by 1.26 (or you can multiply by 0.79), so you would reduce power from 100 watts to 79.4 watts.

A change of 3 dB is accepted as the smallest difference in level that is easily heard by most listeners listening to speech or music. It is a slight increase or decrease in volume.

To produce an increase of +3 dB you simply need to double power (watts).

So, if you are getting 102 dB SPL from 100 watts and you want 105 dB SPL, you will need 200 watts of power. To produce a decrease of –3 dB you need half the power, so you would reduce power from 100 watts to 50 watts (multiply by 0.5 or divide by 2).

Since this 3 dB plateau results in such a happy ratio, it is a very useful relationship to memorize:

2 times the power = +3dB
1/2 the power = –3dB

A change of 6 dB is accepted as a significant difference in level listening to speech or music. It is a quite noticeable increase or decrease in loudness.

To produce an increase of +6 dB you need to increase power (watts) by a factor of four. So, if you are getting 102 dB SPL from 100 watts and you want 108 dB SPL, you will need 400 watts of power (it adds up fast, doesn't it?). To produce a decrease of –6 dB you need to divide the reference power by 4 (or multiply by 0.25), so you would reduce power from 100 watts to 25 watts.

This 6dB plateau also results in happy ratios that should be memorized:

4 times the power = +6dB
1/4 power = –6dB

A change of 10 dB is accepted as the difference in level that is perceived by most listeners as twice as loud or half as loud.

To produce an increase of +10 dB you need to increase power (watts) by a factor of 10. Yes, to get twice as loud, **you need ten times the power!!!**

So, if you are getting 100 dB SPL from 100 watts and you want 110 dB SPL, you will need 1,000 watts of power. To produce a decrease of –10 dB you need to divide the reference power by 10 (or multiply by 0.10), so you would reduce power from 100 watts to 10 watts.

The 10dB Rule should also be memorized:

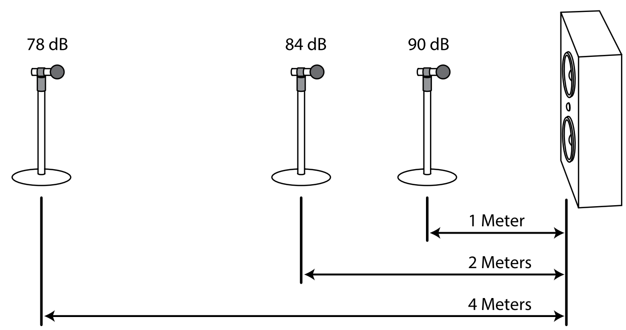
10 times the power = +10dB
1/10 power = –10dB

Here is a handy summary table which also lists the change in voltage and speaker excursion for each change in level:

Increases in Power / Voltage / Decibels:
1.26 x power (watts) = 1.12 x voltage/excursion = +1dB
1.59 x power (watts) = 1.26 x voltage/excursion = +2dB
2.00 x power (watts) = 1.41 x voltage/excursion = +3dB
2.52 x power (watts) = 1.59 x voltage/excursion = +4dB
3.18 x power (watts) = 1.78 x voltage/excursion = +5dB
4.00 x power (watts) = 2.00 x voltage/excursion = +6dB
5.04 x power (watts) = 2.24 x voltage/excursion = +7dB
6.35 x power (watts) = 2.52 x voltage/excursion = +8dB
8.00 x power (watts) = 2.83 x voltage/excursion = +9dB
10.0 x power (watts) = 3.16 x voltage/excursion = +10dB

Decreases in Power / Voltage / Decibels:
0.79 x power (watts) = 0.89 x voltage/excursion = –1dB
0.63 x power (watts) = 0.79 x voltage/excursion = –2dB
0.50 x power (watts) = 0.71 x voltage/excursion = –3dB
0.40 x power (watts) = 0.63 x voltage/excursion = –4dB
0.31 x power (watts) = 0.56 x voltage/excursion = –5dB
0.25 x power (watts) = 0.50 x voltage/excursion = –6dB
0.20 x power (watts) = 0.45 x voltage/excursion = –7dB
0.16 x power (watts) = 0.40 x voltage/excursion = –8dB
0.13 x power (watts) = 0.35 x voltage/excursion = –9dB
0.10 x power (watts) = 0.32 x voltage/excursion = –10dB

Sound pressure changes relative to distance:
As you move away from a sound source, the intensity of the sound diminishes -6 dB for every doubling of distance from the source and increases +6 dB for every halving of distance. So, if you measure 90 dB of sound pressure at 1 meter of distance, you should measure 84 dB at 2 meters, 78 dB at 4 meters, etc.



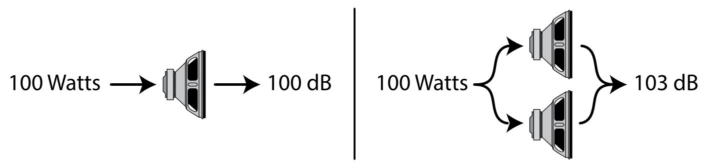
This is why you should never put your ear up next to a speaker that is playing even at moderate levels. Things get really loud as you get closer.

Disclaimer: The above 6dB rule assumes no reflective surfaces, so it is not always accurate in practice (especially in the car). The loss in a car will be less than 6 dB for a doubling of distance if you include the reflected energy in your measurement.

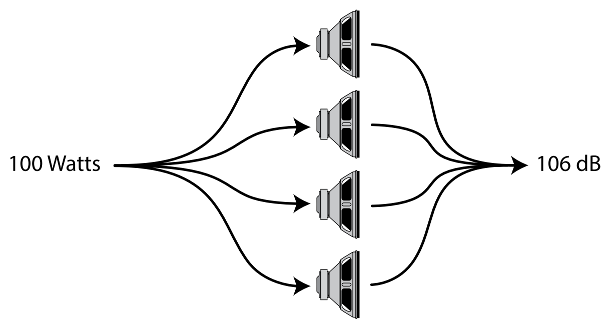
Sound pressure changes relative to number of speakers (piston area):
Doubling the number of sound sources with equal power and equal energy results in an increase of +6 dB. Doubling the number of speakers (piston area) playing the same signal without increasing total power results in an increase of +3 dB. Some examples will help explain this:

First let's assume we're just adding speakers without adding power:

If one speaker is playing at 100 dB SPL with 100 watts of power, adding a second identical speaker (twice the piston area) sharing the 100 watts of power with the first speaker (each speaker gets 50 watts), will increase your sound pressure level +3 dB.

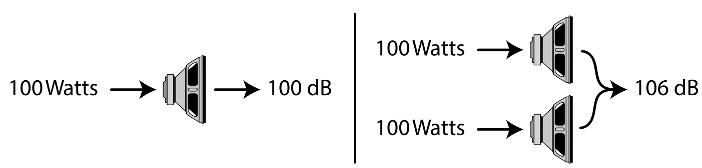


If you now add two more speakers (double the piston area again), for a total of four sharing the same 100 watts (25 watts each), you will have a +6dB increase in sound pressure level over the single speaker.

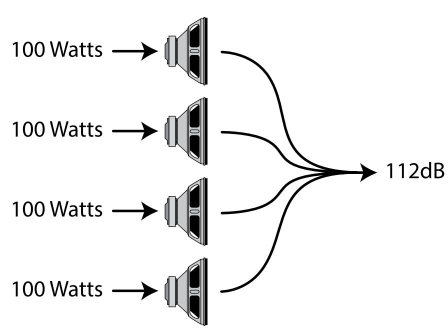


Next, we'll assume that we're adding equally powered speakers and doubling the power:

If one speaker is playing at 100 dB SPL with 100 watts of power, adding a second identical speaker, also powered with 100 watts of power (200 watts total), will increase your sound pressure level +6 dB.



Doubling the number again to four total speakers, each with 100 watts of power (400 watts total), increases your sound pressure level +12 dB over the single speaker.



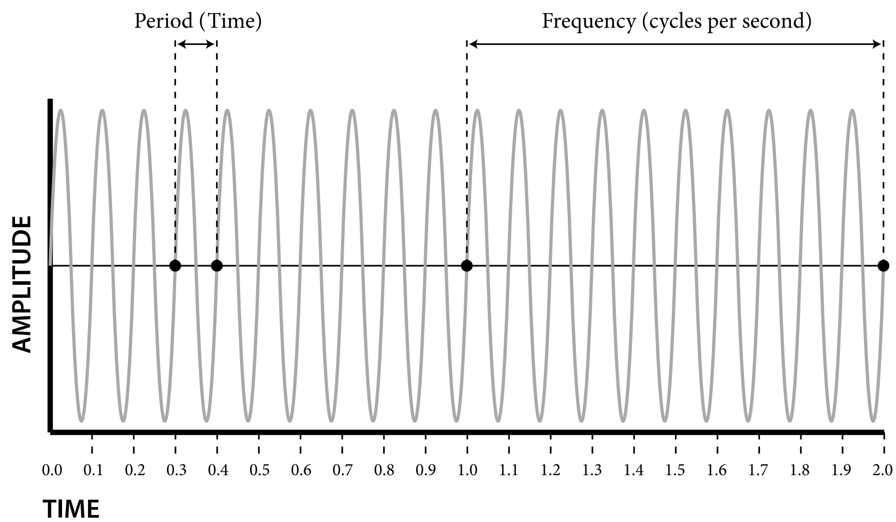
An easy way to keep this straight is to separate the power increase from the speaker increase. We know that doubling the number of speakers (without adding power) gives us +3dB and we also know that a doubling of power gives us +3dB for a total of +6 dB. (By keeping the two conditions separate we can avoid confusion.)

Module 3: All About Waveforms (Music)

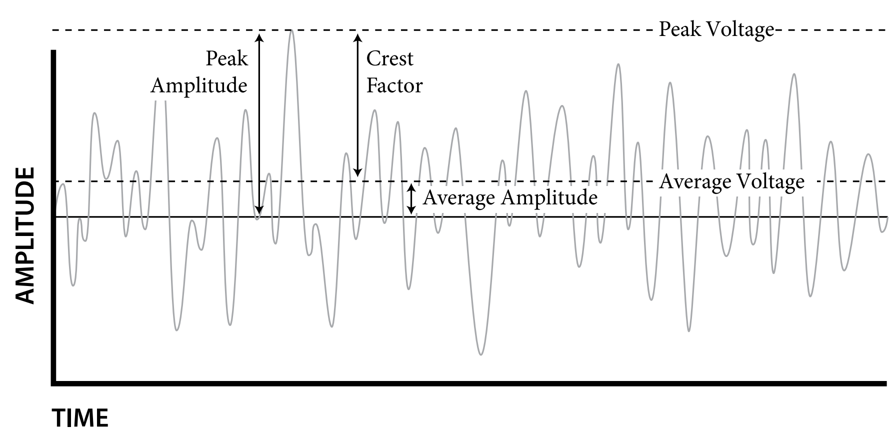
Music signal waveforms are AC signals, meaning that they reverse polarity... this also describes the behavior of sound waves. A DC signal would make no sound because a repeating vibration is not created in the air. Only an AC signal can create a repeating vibration.

To describe waveforms, we need to understand a few terms:

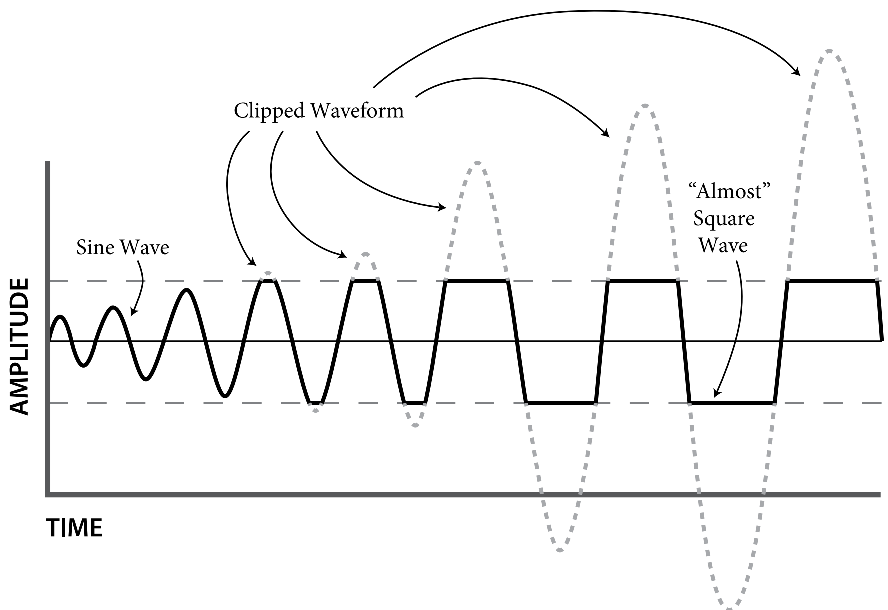
- **Frequency** – the rate of cycle repetition of a wave (cycles per second or Hertz (Hz))
- **Wavelength** – the physical distance covered by a single cycle of a wave. This is calculated by taking the speed of sound (1125 ft / sec.) and dividing it by the frequency.
  Example: 1125 / 50 = 22.5 feet = wavelength of 50 Hz wave.
  For metric users, you would take the metric speed of sound (343 m / sec.) and divide it by the frequency (50 Hz) = 6.86 m
- **Period** is the time it takes for a single cycle of a wave to develop. The period is the reciprocal of the frequency, so for a 50 Hz signal, the period is 1/50th of a second... for a 250 Hz signal it is 1/250th of a second
- **Amplitude** is the strength of the signal or sound (usually expressed in Volts).



- **Dynamic Range** is the difference between the peak level of a signal and its minimum level (expressed in dB).
- **Crest Factor** is the difference between the peak level of a signal and its average (RMS) level (expressed in dB).

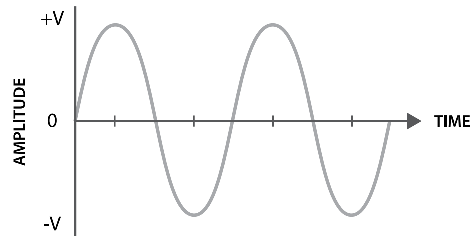


- **Harmonics** are frequencies that are direct multiples of a signal's fundamental (lowest) frequency. For example, the harmonics of 1 kHz are 2 kHz, 3 kHz, 4 kHz, 5 kHz, etc.
- **Periodic** describes waves that repeat the same waveform over and over again and produce a fundamental tone. Sine waves and square waves are periodic signals.
- **Aperiodic** describes waves that do not repeat at a fixed time interval and do not produce a fundamental tone. Random noise is an example of an aperiodic signal.
- **Clipping** describes the behavior of an electronic circuit (amp, for example) being driven beyond its maximum voltage capability, resulting in the "clipping" off of the top of the waveform it is supposed to be reproducing. This clipping creates harmonic distortion.



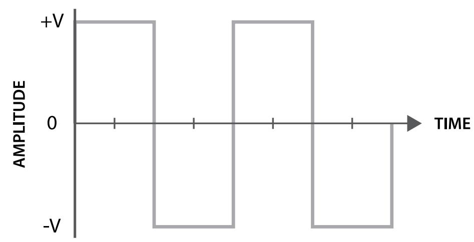
Sine Waves

The simplest waveform is a sine wave, which sounds like a pure tone. A pure sine wave is periodic, has a constant amplitude (loudness) and has a spectral content limited to a single frequency. The crest factor of a sine wave is always 3 dB, meaning that its peak level is 3 dB higher than its average level.



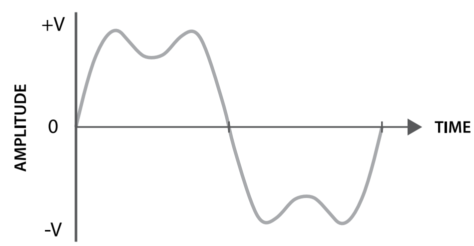
Square Waves

Another simple periodic wave form is a square wave. A square wave does not sound like a simple tone, because the squared off portion of the wave produces harmonics (additional output at frequencies above the fundamental frequency). The crest factor of a square wave is 0 dB, meaning that its peak level is exactly the same as its average level. Square waves do not sound very musical and are fatiguing to the ear. They are often produced by amplifiers or other electronics being "clipped" (driven beyond their clean output limits).



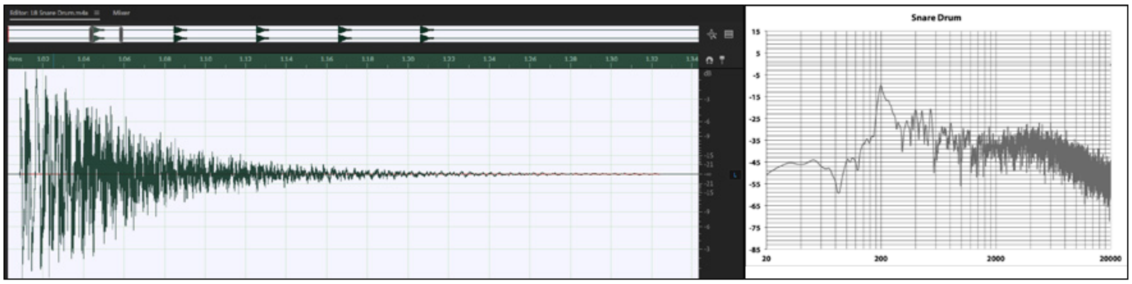
Complex Periodic Waves

If you combine two or more sine waves into one signal, you get a combination of the two single- frequency sounds into one signal. This results in a complex periodic wave with spectral content at a number of different frequencies. The crest factor of a complex periodic wave can vary greatly depending on its characteristics.



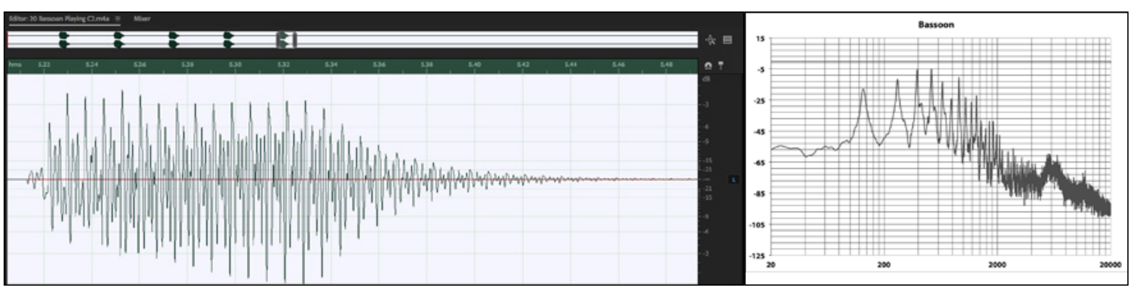
The Sound of Real Instruments

Real instruments and voices produce complex waveforms that combine both aperiodic and periodic waveforms. For example, a snare drum being struck produces rich aperiodic waves at the beginning of its sound (when the stick strikes it), referred to as “attack”. This initial “attack,” then turns into periodic waveforms as the drum’s resonance continues to produce sound after the strike. The “tail” of the sound as the energy dies away is referred to as “decay”. The characteristics of the attack and decay of an instrument’s sound are one of the things that give it its individual, characteristic sound.

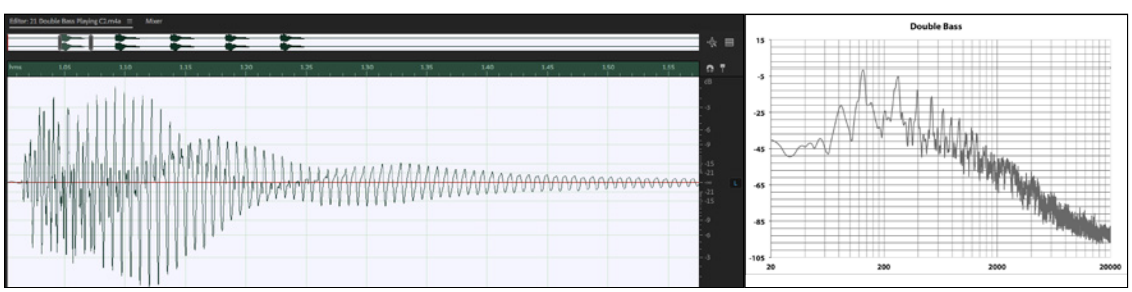


As you can see in the spectral plot above, the snare also produces sound over a very wide frequency range (from about 250 Hz, all the way up to 20 kHz; almost seven octaves!). This output above the fundamental frequency is the result of harmonics (multiples of the fundamental resonances of the drum) which are equally important in defining the snare drum’s sound. In the following examples, we compare a piano, bassoon and double bass, playing the same note (fundamental frequency), but producing different “attacks”, “decay” and harmonics. This should illustrate why these instruments sound different even though they are “playing the same note”.

Piano playing C2 (65.4 Hz fundamental).



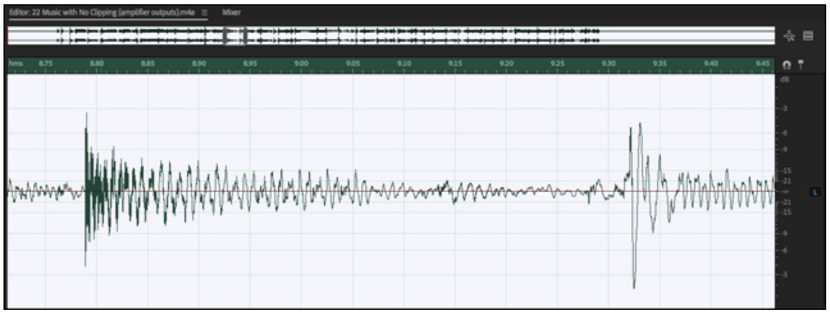
Bassoon playing C2 (65.4 Hz fundamental).



Double bass string instrument playing C2 (65.4 Hz fundamental).

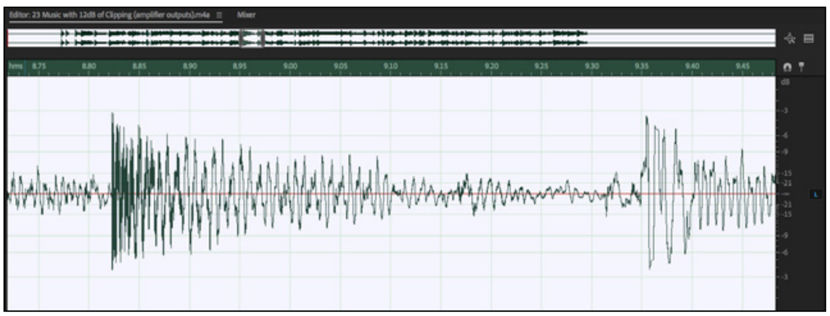
More on the topic of clipping:

Earlier, we learned the definition of clipping and looked at it graphically using a sine wave as an example. Now we will look at clipping with real music. The following three charts show the actual output of an amplifier (one channel of a JL Audio 300/4) playing the same portion of a dynamic musical track at three different levels of clipping.



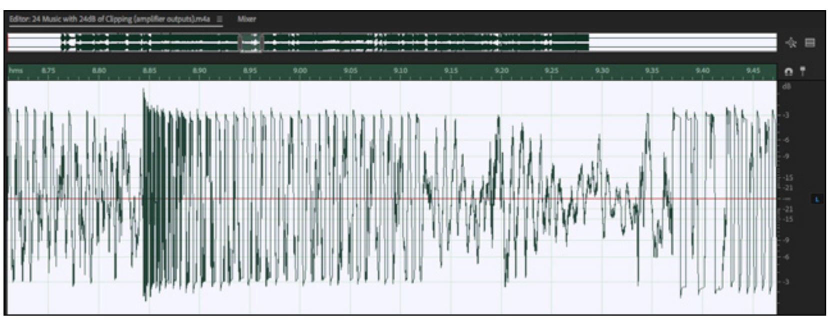
Crest Factor: 20.4 dB

1) One channel of 300/4 at full output (no clipping)



Crest Factor: 17.5 dB

2) 300/4 trying to reproduce music 12 dB above clipping level - this amount of distortion is actually tolerable to many people



Crest Factor: 7.9 dB

3) 300/4 trying to reproduce music 24 dB above clipping level - this amount of clipping is not tolerable for anyone (we hope).

This is what clipping looks like with real music. It is also what is being sent to your speakers.

Module 4: Loudspeaker Power Handling

An understanding of power handling and what contributes to it is essential in order to design reliable, great sounding systems. Driving speakers with appropriate power levels is important to everyone; car audio customers want reliable systems, the retailer and speaker manufacturer don't want warranty headaches. In this module, we will discuss speaker power handling in detail and discuss how to make smart choices in matching speaker systems to amplifier systems.

We all know that speakers move when we apply power to them, that's how they make sound. The mechanical motion of the speaker is controlled by the speaker's motor, suspension and the enclosure it is operating in. Every speaker has limits to how much it can move without bad things happening. **This limit is known as the mechanical power handling.**

The mechanical motion of a speaker is quite violent. Think of a woofer reproducing a 50 Hz signal; it is being asked to move back and forth 50 times a second, which subjects it to significant acceleration and deceleration forces. A component woofer is moving back and forth between 80 and 5,000 times a second. Low frequencies require greater back and forth movement (excursion) than high frequencies. The more we ask a speaker to move, the greater the acceleration and deceleration become and the greater the stresses placed on glue joints, spider materials and surround materials. By avoiding damaging power levels, you minimize the stress on these parts.

At the extreme limits you also have to be concerned about collisions between the moving parts of the speaker (spider, surround, voice coil former, etc.) and its non-moving parts (back plate, basket, top-plate etc.), also known as "bottoming out". Most people will avoid collisions because they are plainly audible and sound awful, but knowing when a speaker is being mechanically stressed, without bottoming out, is harder. The damage occurs over a long period of time as the speaker's suspension gradually fatigues. Avoiding power levels that produce elevated stress benefits everyone.

As the name implies, **thermal power handling** refers to how much heat a loudspeaker can dissipate without significantly compromising performance and/or failing completely.

When voice coils heat up beyond their comfort zone, their resistance to electricity goes up, resulting in an increase of impedance. This increase of impedance reduces power in the coil, resulting in reduced output. This phenomenon is referred to as **power compression**.

Continuing to drive a speaker at high volume levels when it is already hotter than its comfort zone will eventually lead to complete failure of the speaker (a burnt voice coil).

Fundamentally, loudspeakers are very simple machines which use alternating current (AC) flowing through a moving coil and reacting to a fixed magnetic circuit to produce positive and negative linear motion of a diaphragm. This motion creates audible vibrations in the air which, if everything is working right, are very similar to the AC signal feeding the speaker in the first place.

This AC signal is supplied by an amplifier and it has to be powerful enough to motivate the speaker and overcome its inefficiencies. An automotive subwoofer driver, being an incredibly inefficient pig of a device, only uses about 0.5% to 1% of the amplifier's power to do any effective work (motion), the rest of the power becomes heat in the voice coil (very much like the coils in an electric stove). If that heat isn't removed from the voice coil, the shiny stuff that coats (and insulates) the coil begins to burn off and if you don't stop, you end up with that unpleasant smell in your car, a curious lack of output from your subwoofer and a dent in your wallet.

Subwoofers get rid of voice coil heat by transferring that heat to the metal parts of the motor (the top-plate and pole-piece primarily). These heavy metal parts act like big heat sinks and help to remove heat until they themselves get so hot that they stop helping. To keep the metal parts cool, some designs employ a pole-vent, frame venting and other methods to help blow some air around the metal parts, which helps to some extent.

Despite all these cooling aids, there is a limit to any subwoofer's ability to get rid of voice coil heat and it is important to understand what causes failures so as to avoid them during the design phase of the system. The bottom line of why voice coils burn is quite simple:

Excessive average power applied over time burns voice coils.

When it comes to subwoofers, that's pretty much all there is to it, there's no "rest of the story" or exception to the rule.

Let's really analyze this statement to ensure its clarity. Excessive power by itself won't usually burn a coil on a subwoofer. They can handle huge amounts of power in very short-duration bursts. For the coil to be burnt, the excessive power must be applied over a long period of time. This is why it is useful to distinguish between peak power in a musical signal and average power. The peak power might rip a surround or damage a spider, but it doesn't last long enough to overheat a coil (unless we have a really silly "arc-welder class" amplifier on a fairly modest voice coil). The peak power barely tickles the coil thermally. It is the average power in the signal that heats up the voice coil until it gives up its smoke. You would think that this simple fact is understood by most audio enthusiasts, but it isn't. Here are some prime examples of the mythology surrounding power handling:

"Having too little power blows woofers."

or

"Clipping, by producing harmonic distortion and/or DC, blows woofers."

or

"You need to run at least twice the power that the subwoofer is rated for if you want it to get loud."

or

"I can control how much power gets to the subwoofers by setting the amplifier "gain" low."

or

"You're not getting your money's worth if you don't have enough power to reach your woofer's excursion limits."

or

"Big woofers need more power than small ones to get loud."

These statements are like really bad urban legends; No matter how many times reasonable people debunk them, they resurface again and again. Before we analyze these pearls of wisdom, let's go over the two basic truths about car audio users as they apply to the power handling issue.

Basic Truth #1: A typical user will frequently operate an audio system well beyond its clean output capability, regardless of gain settings, dealer advice or common sense... especially when a friend (or two) sit in the car. This means that the subwoofer amplifier will be driven well into clipping regularly (10 dB of clipping is not uncommon). Even "golden-ears" can tolerate fairly high distortion levels, especially at low frequencies, so don't believe for a minute that they won't clip their amp, either.

Basic Truth #2: A user will almost never say: "It was my fault, I was just listening too loud for too long". Instead, you'll hear something along the lines of:
"I was listening to the news when it happened"
"This woofer sucks, I want a new one, now!"
"It was working fine last night, but this morning I got in the car and my woofers were dead." (And they won't bring their two friends who witnessed the three-hour Bass Mekanik-clip-fest that caused the failures.)

Because we consider these truths to be self-evident (and keeping in mind that we can't hook customers up to polygraph machines), we should address these common misconceptions so as to determine an intelligent course of action in setting up amplifier/ subwoofer systems.

"Having too little power blows woofers"

Let's think about this gem for a minute. If this were true, every time we turned our system down to a low volume level, we would blow the woofers. This would be quite aggravating (and expensive). Fortunately, it's utter nonsense. Remember that the converse is true; Too much average power over time blows woofers.

"Clipping, by producing harmonic distortion and/or DC, blows woofers."

The idea behind this myth is that a clipped signal contains a heavy harmonic distortion component which can be damaging to voice coils. The problem is that it's dead wrong. The harmonic content of the clipped signal is not the culprit at all (the inductance of the woofer pretty much annihilates any high frequency harmonic energy. For high frequency drivers, this can be a contributor, but not for subwoofers). DC (direct current) isn't the culprit, either. Amplifiers do not produce significant DC when clipped unless the amplifier was designed by Cro-Magnon man. Even cheap, flea-market amplifiers with flashing lights and thermometers on the heat sink don't have a problem with this.

Special Note: You may think you can prove us wrong by connecting a multimeter set to DC voltage mode to an amplifier's outputs and measuring "DC voltage" of some value, but the only thing you've actually proved is that music signals and output stages are not always symmetrical, and these asymmetries are misread by the meter as a fluctuating DC value. You're not actually reading direct current.

The real villain is dynamic range compression, which refers to an increase in the amount of average versus peak energy of the amplifier's output signal when it is overdriven (clipped). When an amplifier clips, the short duration peaks of the music are chopped off, but the average level of the signal is allowed to run higher than it would if the amplifier were operating below clipping. The short duration peaks don't last long enough to worry about in most cases, but the increases in average power level build heat up very quickly in a voice coil and are the direct cause of burnt voice coils. A heavily clipped 250-watt amplifier is able to deliver similar average power as an unclipped 500-watt amplifier. So, it's not the distortion associated with clipping that is blowing speakers, it's just good old excessive average power over time heating the voice coil and causing it to burn.

"You need to run at least twice the power that the subwoofer is rated for if you want it to get loud."

This type of statement is really dangerous, because it leads people to make very poor decisions when matching amplifiers to woofers. A manufacturer's power handling ratings are intended as a guideline for amplifier matching, taking into account real-world car audio conditions and typical user behavior. It is bad enough when someone severely overdrives a 500-watt amplifier to a 500-watt subwoofer system (remember that it behaves similar to a 1,000-watt amplifier when overdriven). Remembering Basic Truth #1 and keeping in mind that an overdriven 1,000-watt amplifier will behave like a 2,000-watt amplifier in terms of average power, we can reasonably conclude that it is not a good idea on a typical 10-inch woofer.

The notion that the system will not be loud with its rated power is also misguided. Properly rated subwoofer systems will operate comfortably with amplifiers rated close to the subwoofer system's rated power and will produce most of their ultimate potential without inviting thermal or mechanical distress. Squeezing the last little bit of performance by overpowering the subwoofers will not sound much louder but will compromise reliability in real-world use. For example, if a single 12-inch woofer is playing comfortably at 130 dB with a 500-watt amplifier (its rated power), 1,000 watts might make it play 1.5 – 2 dB louder, which is a **barely noticeable** difference. You might expect 3 dB more with twice the power, but you won't get it if the voice coil is being overheated and in power compression, reducing effective power. With a 1,000-watt amplifier, driven into clipping, the 12-inch woofer is subjected to excessive heat / mechanical distress and is far more likely to fail than with a 500-watt amplifier. Why over-stress the woofer for a barely noticeable increase in output?

Then there is the weekend SPL warrior. These users enjoy the challenge of competing in SPL competition with their daily driven vehicles and systems. Because of this, they generally seek as much power as possible to maximize their scores and 1 or 2 dB really matter in this game. A subwoofer system can handle a lot of power in short duration bursts to achieve high SPL readings if the system is properly set up and operated (which is hard to do). If the wrong frequency is chosen for the "burp", disaster can strike, ripping the speaker's suspension or glue joints. If the competitor gets carried away trying to better the score without realizing that it's not going to happen by clipping the amp even more; coils will burn (especially with big amplifiers). Needless to say, the subwoofers become the "whipping boys" for any errors the competitor may make in the heat of battle.

To make matters even worse, when SPL competitors drive their cars around town listening to music with their overpowered setups and they apply this power for long periods of time, problems will arise (not the least of which is hearing damage). The only answer to this issue is to educate the user and explain that there is a significant reliability penalty for extreme power applications (anything more than twice the speaker's rated power handling) and that driver failures resulting from extreme high-power applications are not covered under warranty. There are also severe compromises inherent in designing a high SPL subwoofer enclosure.

These are generally large ported boxes with high tuning frequencies which are ill-suited for reproducing broad bandwidth material (like music) and are very prone to allowing over-excursion at very low frequencies, leading to ripped surrounds and spiders.

No one expects a car manufacturer to rebuild a transmission under warranty for a nitrous-injected, methanol burning, way over boosted, 10-second drag racer, right? If someone wants to compete at the extreme limits then they need to accept responsibility for breaking stuff.

"I can control how much power gets to the subwoofers by setting the amplifier gain low."

No, you can't. The input sensitivity control (commonly referred to as "gain control") of an amplifier simply adjusts the amplifier's input preamp section to a voltage range that is compatible with the head unit or processor in front of it. It is not a power control, it is a level-matching control. If you deliberately turn the input sensitivity down to limit power, nothing prevents the user from turning up the bass on the head unit, equalizer, bass processor or amplifier boost circuit to get more output from the amplifier and the subwoofer system. Nothing prevents the user from finding the input sensitivity control and setting it higher, either. If they don't know how to do it, their friend will show them how.

"You're not getting your money's worth if you don't have enough power to reach your woofer's excursion limits."

This might be true if you're performing experiments aimed at breaking the SPL world record and have an unlimited budget for woofers, but it is a totally ridiculous statement for real-world car audio systems. Think of it this way, you can eventually bottom any vehicle's suspension if you're crazy enough, even a Baja 1,000 off-road racer. This doesn't mean it's a good idea. The engineers of the Baja truck try really hard to make sure it doesn't happen, and so do the drivers (if they want to finish the race).

The point of car audio is not to break speakers; it is to reproduce music at enjoyable levels. When manufacturers design long-excursion capability into their woofers, they do so to enhance their ability to reproduce low-frequencies and to have a wide safety margin between the woofer's intended operational power range and its mechanical and physical limits. This way, the mechanical limits stay out of the way of the speaker's operating envelope, leading to better fidelity and long-term reliability.

Problems will be created by those who seek to find the limits of any speaker. You are not discovering anything special by bottoming out a woofer, only the fact that the enclosure is poorly designed, or you have way more power at your disposal than you actually need for that subwoofer system. It's all about operating the system within its limits, not at or above its limits.

"Big woofers need more power than small ones to get loud"

This one is a classic. Very often we hear of people who have been told that a larger speaker, like a 15-inch subwoofer needs more power than a 10-inch subwoofer. This is completely backwards. Smaller subs are almost always **less efficient** than bigger subs. For a given amount of output, the bigger speaker will generally require less power than the small one to play as loud. To use a real-world example, a 13W7AE will be louder than a 10W7AE with 500 watts of power, thanks to more than twice the piston area. There is nothing wrong or wimpy about driving a sub with less power than it is rated to handle. It is actually a pretty smart thing to do for abusive users. You don't have to nuke the voice coils with kilowatts to get the advantage of using larger speakers.

FOR JL AUDIO DEALERS:

"JL Audio woofers are way underrated, you can put a lot more power into them."

Compared to other companies' ratings, our power handling ratings might seem low, but they are honest recommendations that will give the user excellent performance and reliability. We test all our products according to stringent EIA test protocols as well as proprietary methods to arrive at our recommendations. We are not interested in overstating the product's capabilities. We strive to offer useful recommendations that you can trust.

The continuous power handling rating of the woofer is JL Audio's recommendation or the amount of rated continuous (RMS) amplifier power output to be used on that woofer. This recommendation assumes that the user will listen to music for extended periods of time, while moderately (but regularly) clipping the amplifier.

For example, a 10W7AE is rated for 750 watts. This means that we recommend an amplifier rated for around 750 watts continuous (RMS) power output (like the HD750/1). Two 10W3v3's are rated for 1,000 watts (500 watts each), so you should recommend amplifiers with approximately 1,000 watts continuous (RMS) output (that HD750/1 is a pretty good match up, as is the HD1200/1). An HD1200/1 would be a questionable choice on a single 10W7AE, and a pair of HD750/1 would be pushing things a bit on two 10W3v3s.

JL Audio Power Recommendation Chart

We include this chart in new product data sheets, product literature and it is also available on our website (www.jlaudio.com). In this chart we show the "power handling envelope" of each of our subwoofer drivers. The range of recommended power for each model shifts in color from green (minimum) to yellow (optimum) to red (danger zone) as power increases. The green (minimum) zone represents the best reliability, at the expense of some output. The yellow (optimum) zone shows the best balance of output and reliability. The red (danger zone) zone represents optimum output at the expense of some reliability (the operating habits of the user are more significant here). Beyond the red zone, a black bar appears showing excessive power which, if used, voids the subwoofer's warranty.

The red (danger zone) zone should be reserved for experienced (rare) users who understand that they can push the system to the limits for short periods of time but will refrain from playing at those levels for hours on end. If operated with respect, higher powered systems can be reliable. If this level of amplifier power is available to an abusive user, failures are likely.

If you stick to the yellow (optimum) zone, you should have very good performance and reliability for typical (normal) users who like to crank, but are still somewhat sensitive to distortion. You will get 90% of the speaker's available performance, without undue risk of failure.

The green (minimum) zone should be seriously considered for a highly abusive user. "Green zone" power is unlikely to hurt a speaker even if the user is ridiculously abusive. Lots of woofers with a small amount of power on each one is the ticket for success with abusive users. For example, it is way better to use four 12W3v3's with 1200 watts (HD1200/1) than a single 13W3v3 with 1200 watts scorching that one voice coil. The four 12's will be louder and more reliable.

Now that we have thoroughly debunked the myths, let's take a look at how to diagnose failures when they happen and determine corrective actions to hopefully prevent them from recurring.

Failures related to over-excursion:
- *Torn surrounds*
- *Ripped or fatigued spiders*
- *Fatigued or broken lead wires*
- *Glue Joint failures*

Over-excursion can be caused by a few different factors in isolation or in combination. If the box is built properly and to proper specifications, focus on Cause #1:

Cause #1: Too much power (in this case, peak power)
Possible solutions:
- A change in listening habits (unlikely)
- A switch to woofers with more mechanical power handling capability
- Double the number of woofers presently in use (without adding power; effectively reducing the excursion of each driver)
- A less powerful amplifier

Cause #2: A sealed enclosure which is too large and/or seriously leaky.
Solution: Properly build a box with appropriate volume.

Cause #3: A ported enclosure which is too large and/or tuned too high.
Solution: Properly build a box with appropriate volume and port tuning.

Cause #4: A combination of any of the above items.

Failures related to excessive heat:
- *Burnt/delaminated voice coils*
- *Burnt lead wires*
- *Separation of the voice coil former from cone/spider (glue failure)*

The cause: Too much average power over time.
In layman's terms: the amplifier driving the subwoofer(s) is too powerful for the current subwoofer system and the user's listening habits.

Possible Solutions:
- Switch to woofer with more thermal power handling capability.
- Increase (double or triple) the number of woofers presently in use (spread the amplifier power across more voice coils)
- Change to a less powerful amplifier (unlikely to fly)
- Suggest a change in listening habits to the customer (highly unlikely)

Example:

1) A customer just blew up his single, mid-level 12-inch woofer with a 750 watt amplifier. What can you recommend?
   A) An upgrade to a 12-inch woofer with more power handling (will be slightly louder due to less power compression)
   B) Add a second 12-inch woofer (will definitely be louder)
   C) Switch to four 10-inch woofers (will be even louder)

All of the above are viable recommendations... simply swapping the speaker out will not fix the problem, because too much power was sold in the first place.

Option C is the best for the customer. The customer will get more output and better sound quality, and each subwoofer will only need to handle 1/4 of the amplifier's power output, keeping all four cool and happy.

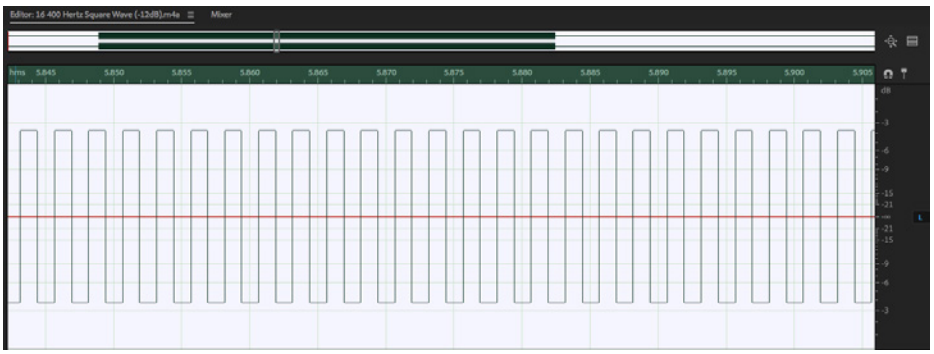
What role does program material play?

The program material (music) played by the user has a huge impact on the average power over time equation. There are two aspects of the program material which have to be looked at to analyze its impact on speaker power handling: Spectral content and crest factor.

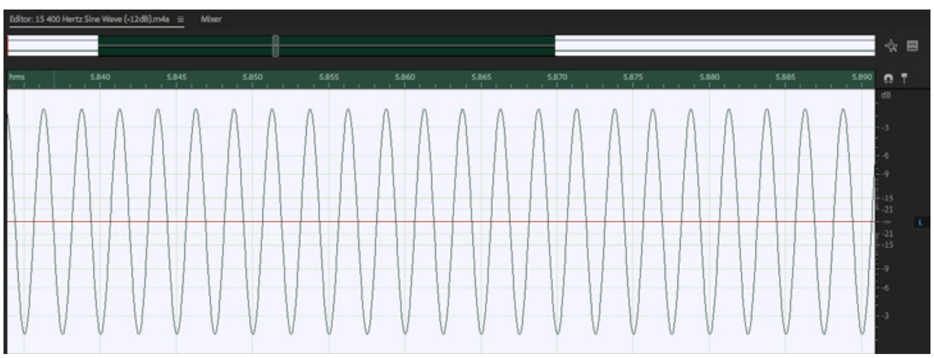
Spectral content simply refers to how much energy the music has across the full range of audible frequencies. “Bass music” for example has significantly more low-frequency content than jazz or rock, and therefore places a greater demand on subwoofer systems. Rock tends to have more relative midrange energy than bass music, resulting in greater demands on component speakers in a system.

Crest factor, as stated earlier in this training, is the ratio of peak energy to average energy of a signal. For example, a pure sine wave has a crest factor of 3dB, meaning that the average power is exactly half of the peak power.

This means that if we run a 100-watt (peak power) amplifier at its full, clean (unclipped) power with a sine wave, the speaker is dissipating 50 watts of average power. (This amplifier would realistically be rated as a 50-watt continuous power amplifier.)



A square wave has a crest factor of 0 dB, meaning that the peak and average power levels are the same. Our 100-watt amplifier would be delivering 100 watts average power to the speaker.



If you play a pure sine wave into a speaker at high power, the voice coil will heat up very quickly because the average power is high. A square wave played at full amplifier power will deliver twice as much power over time as the sine wave, heating the speaker’s voice even more rapidly than the sine wave.

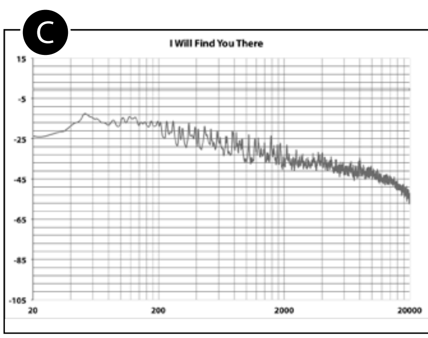
Fortunately, we don’t go around listening to sine and square waves. We listen to music, which has far higher crest factors than these test tones. How much higher? It depends on the recording.

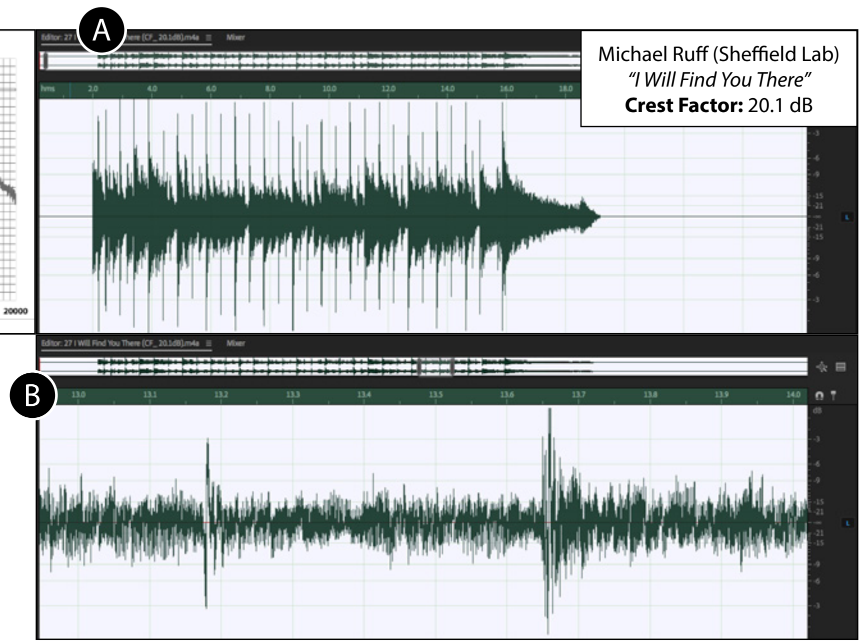
The Audiophile Labels

High-quality “audiophile” music labels (Telarc, Sheffield Lab, Chesky, Wild Child, etc.) generally produce recordings with crest factors approaching 20 dB. This means that our 100-watt amplifier is only delivering around 1 watt of average power into the speaker. If we all listened to this music, speaker failures due to heat would be very rare, indeed. The high dynamics of these recordings are one of the key reasons they sound so good, because they capture the realistic dynamics of the instruments. Another factor to consider is that for a given volume setting, these recordings don’t sound as loud as more mainstream pop recordings. You usually have to turn the volume up a bit when listening to these.

Below we see the actual musical waveform of a 20 second section of one such recording. The top two graphs (A) represent the right and left channels of Michaels Ruff’s “I Will Find You There”. These graphs show amplitude (vertical-axis) versus time (horizontal-axis). The amount of black seen in these plots gives us a visual reference for the average power over time in this track.

The two lower graphs (B) show a smaller portion of time in the recording (about half a second) so we can get a clearer look at the nature of the waveform. The third graph (C) is a frequency plot taken from a section of the recording. This frequency response data tells us how power varies vs. frequency in the track, exactly like an RTA would read it on slow averaging.





Michael Ruff (Sheffield Lab)
“I Will Find You There”
Crest Factor: 20.1 dB

Other Examples Of Audiophile Crest Factors:

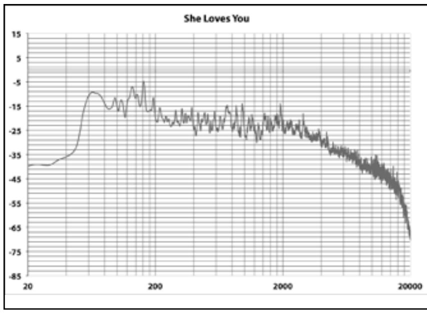
Big Joe Maher (Wild Child)
“Mojo”
Crest Factor: 21.7 dB

Henry Mancini (Telarc)
“Pink Panther Theme”
Crest Factor: 23.8 dB

The average crest factor of the audiophile recordings we analyzed was 21.8 dB. This represents an average power level that is less than 1/100th of the peak power!

Popular Music (1960's and 1970's)

Popular music recordings over the years vary a great deal with regard to crest factor but some clear trends can be defined from measuring multiple examples.



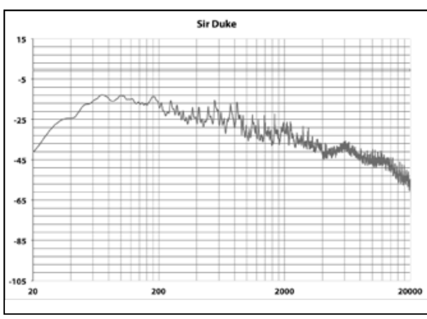
The Beatles
"She Loves You"
Crest Factor: 13.8 dB

Other Examples Of 1960's Crest Factors:

Van Morrison
"Brown Eyed Girl"
Crest Factor: 17.1 dB

Gladys Knight and the Pips
"Midnight Train to Georgia"
Crest Factor: 22.6 dB

The 1960'S: The average crest factor of the 1960's recordings we analyzed was 17.8 dB. In the '60's, despite fairly primitive recording technology, typical popular music releases had crest factors between 13 – 23 dB. Low and high frequency spectral content was fairly limited. A good example is The Beatles' "She Loves You".



Stevie Wonder
"Sir Duke"
Crest Factor: 19.4 dB

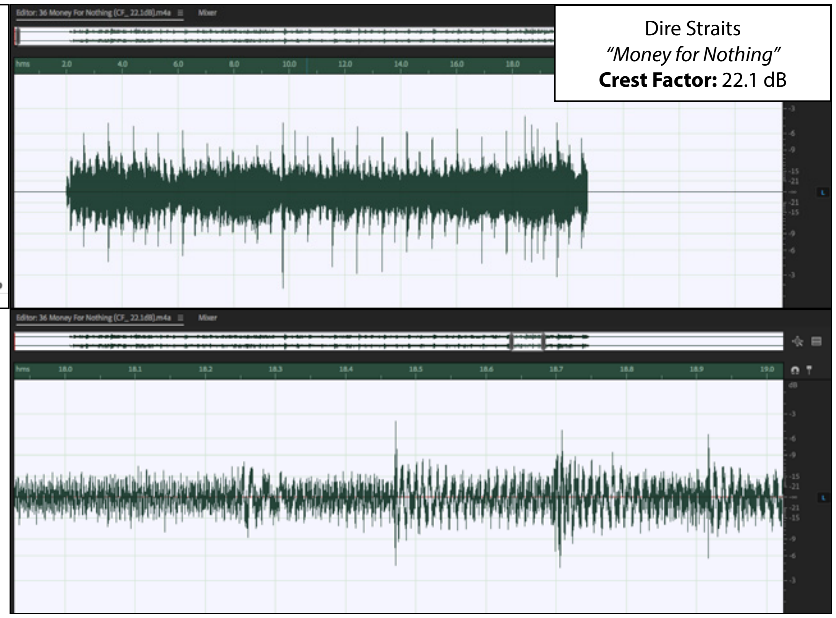
Other Examples Of 1970's Crest Factors:

Santana
"Black Magic Woman"
Crest Factor: 12.0 dB

Tower of Power
"Squib Cakes"
Crest Factor: 19.4 dB

The 1970'S: The average crest factor of the 1970's recordings we analyzed was 16.9 dB. In the '70's recording technology had progressed dramatically. Recordings in this decade had much more low and high frequency content and most also showed very good crest factors. A good example is Stevie Wonder's "Sir Duke". Santana's "Black Magic Woman" was notably weak in crest factor and brings the average down.

Popular Music Labels (1980’s and 1990’s)



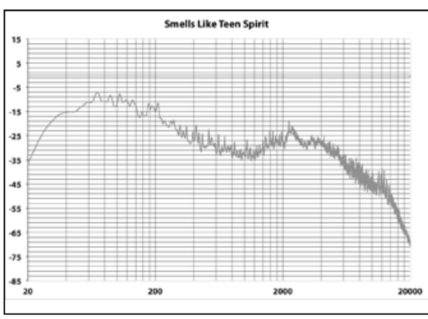
Dire Straits
“Money for Nothing”
Crest Factor: 22.1 dB

Other Examples Of 1980’s Crest Factors:

Talking Heads
“Burning Down the House”
Crest Factor: 23.8 dB

Run DMC
“Walk This Way”
Crest Factor: 20.1 dB

The 1980’S: The average crest factor of the 1980’s recordings we analyzed was 22.0 dB. The ‘80’s were the beginning of the digital era and the absolute peak of analog recording technology. Recordings from this decade had impressive dynamics not too different from the audiophile labels. Dire Straits’ “Money For Nothing” is a good example, and so are the two other tracks listed at left.



Nirvana
“Smells Like Teen Spirit”
Crest Factor: 16.0 dB

Other Examples Of 1990’s Crest Factors:

Red Hot Chili Peppers
“The Power of Equality”
Crest Factor: 19.3 dB

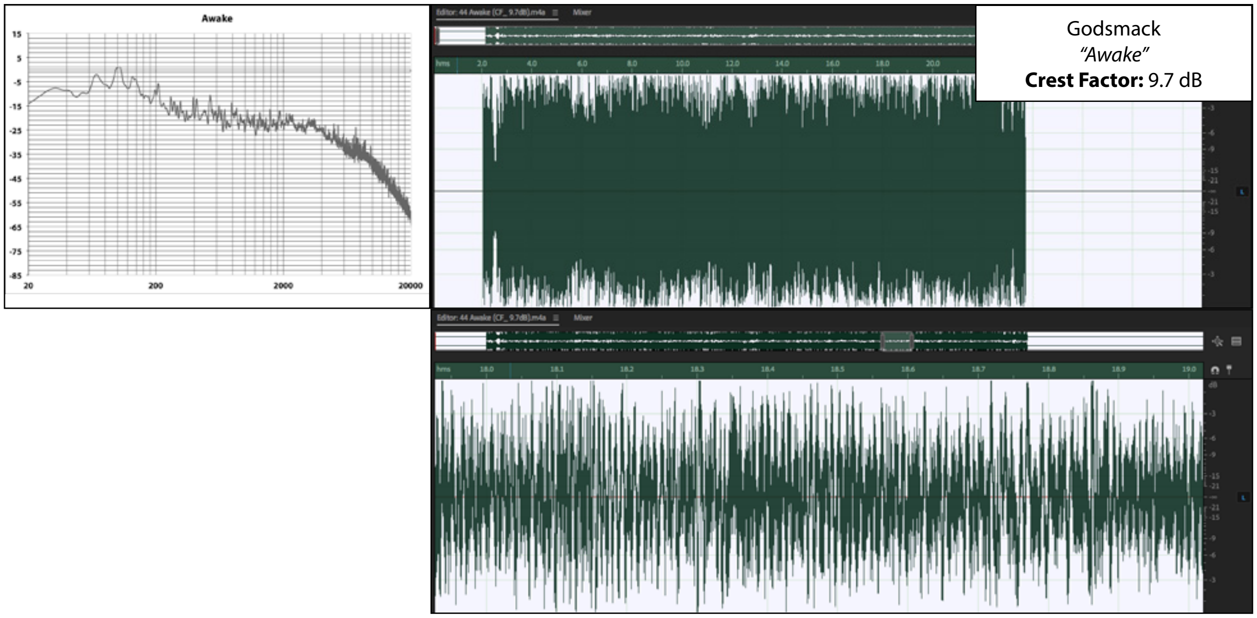
C & C Music Factory
“Everybody Dance Now”
Crest Factor: 19.4 dB

Brooks and Dunn
“Hard Workin’ Man”
Crest Factor: 16.8 dB

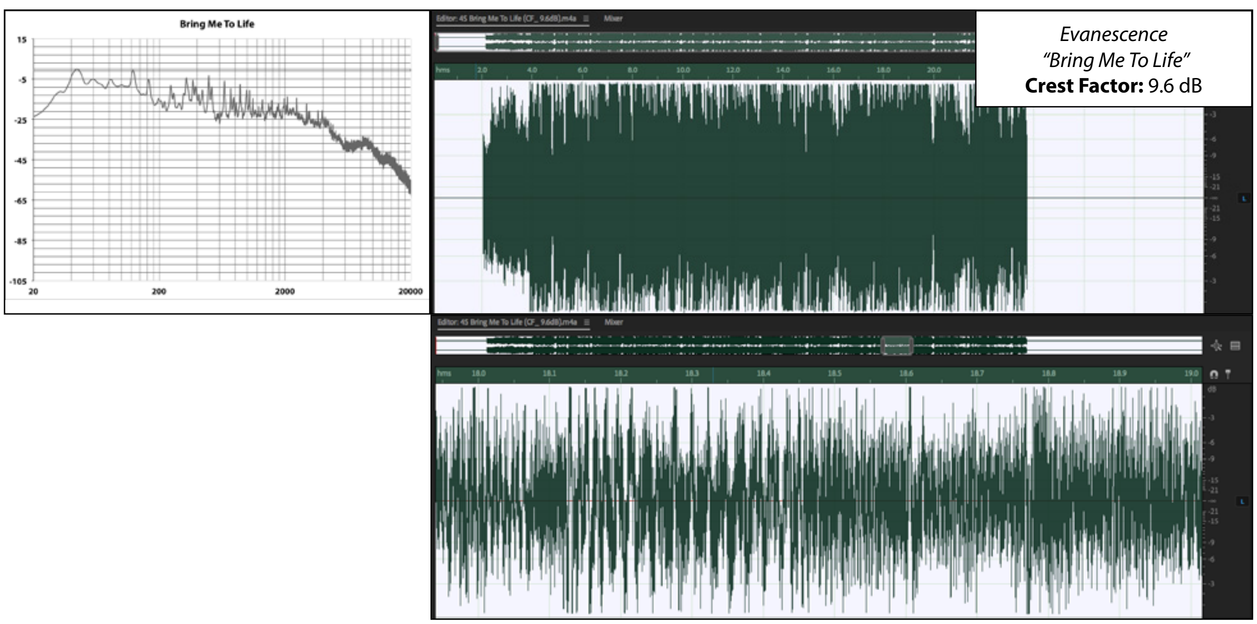
Metallica
“Until it Sleeps”
Crest Factor: 9.5 dB

The 1990’S: The average crest factor of the 1990’s recordings we analyzed was 16.2 dB. Some popular recordings from this decade exhibit high crest factors and very good low and high frequency extension. Even Nirvana’s “Smells Like Teen Spirit”, which was intended to sound “grungy”, had a reasonable crest factor. Only Metallica’s “Until it Sleeps” belongs in the “Dynamics Hall of Shame”.

Popular Music Labels (2000's)



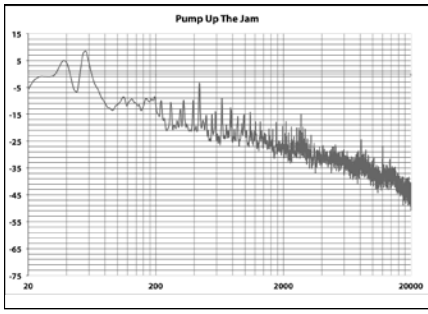
Godsmack
"Awake"
Crest Factor: 9.7 dB

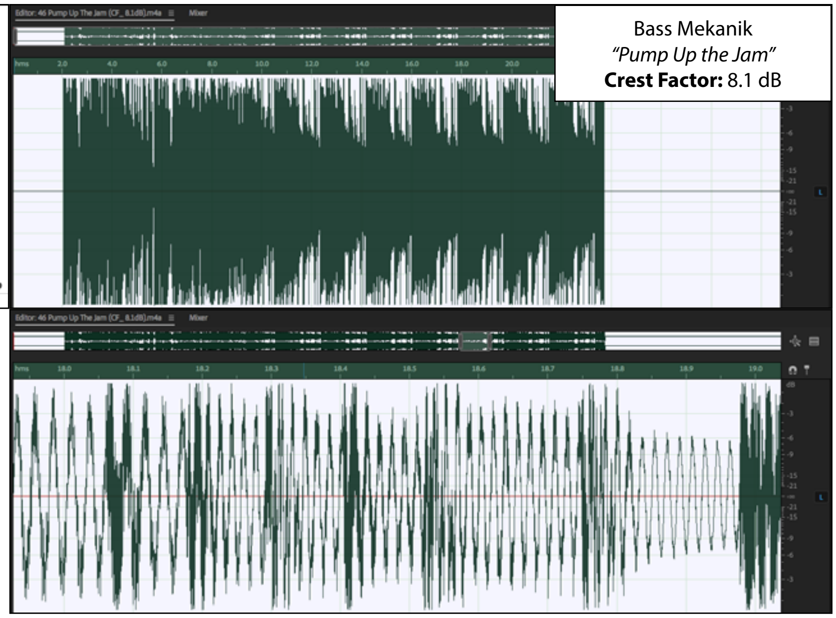


Evanescence
"Bring Me To Life"
Crest Factor: 9.6 dB

The 2000'S: The average crest factor of the 2000's recordings we analyzed was only 10.1 dB!!!
In the last few years, recordings have become extremely compressed in order to make the music sound "louder" on cheap systems. It seems that music producers are less concerned about high fidelity and more concerned about creating "loud sounding" recordings. This practice represents a significant decline in fidelity due to the fact that the natural dynamics of instruments is not being accurately represented. These compressed modern recordings have less crest factor than the Beatles' "She Loves You", which was recorded over fifty years ago!!! **The over-use of compression has led to a gigantic leap in average power, compared to earlier recordings.**

Popular Music Labels (2000's continued)





Bass Mekanik
"Pump Up the Jam"
Crest Factor: 8.1 dB

Other Examples Of 2000's Crest Factors:

Linkin Park
"Somewhere I Belong"
Crest Factor: 8.4 dB

Santana
"The Game of Love"
Crest Factor: 10.1 dB

Shakira
"Tango"
Crest Factor: 11.0 dB

Eminem
"Lose Yourself"
Crest Factor: 11.0 dB

4 Strings
"Diving"
Crest Factor: 11.9 dB

50 Cent
"In Da Club"
Crest Factor: 10.8 dB

No Doubt
"Hey Baby"
Crest Factor: 9.5 dB

What can we learn from these charts?

Our customers typically don't listen to Sheffield Lab, Telarc or any other audiophile recordings. Most of them listen to music that is currently popular. For this reason, we have to be keenly aware of the nature of current recordings when we design sound systems.

Current jazz and classical music recordings are about the only ones with consistently decent crest factors (above 15 dB). Beyond these genres, the overuse of compression is running rampant in the music industry. The pressure to make popular music sound louder on the radio and on low-fidelity equipment is to blame for this phenomenon. The crest factors of bass music, hip-hop, R&B, modern rock, modern pop, modern Country Music, Latin music, even popular jazzy stuff like Norah Jones' multiple Grammy winning album are now, sadly, in the 9-12 dB range.

Not only do the older recordings sound better than over compressed "modern" recordings, but they are also far less demanding on audio systems. **Dire Straits' "Money for Nothing", for example, has a crest factor of over 22 dB, so it will deliver less than 1/10th the average power as Godsmack (9.7 dB crest factor) at the same volume setting.**

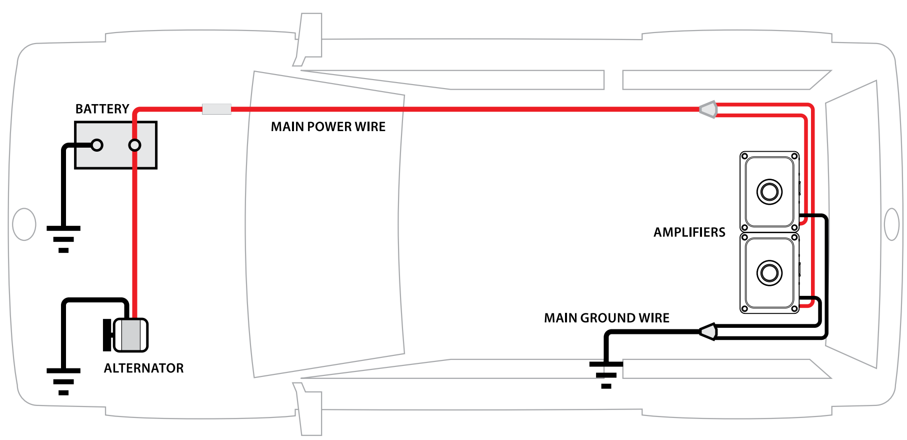
This means that we have to be very concerned about average power over time. If a user is listening to Godsmack loud on a 1,000-watt system without ever clipping the amplifiers (not likely at all), the average power over time is approximately 100 watts, which is probably survivable for the speaker system and comparable to clipping "Money For Nothing" pretty severely. If the listener cranks it up further and clips Godsmack by 10 dB, which is not uncommon, the amplifiers will produce almost their full rated power (1,000 watts in this example) as an average power level. Essentially, the crest factor is severely compressed to near 0 dB, which puts the speaker system in danger and taxes the amplifiers and vehicle charging system. **Pretty scary stuff to think about the next time you want to sell someone twice the amplifier power the speakers are rated for!**

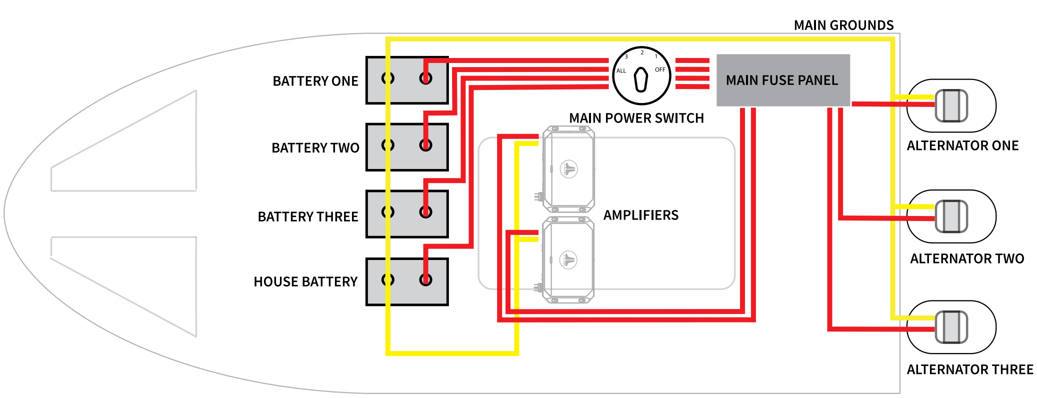
Module 5: Charging System Fundamentals

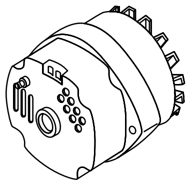
Understanding the charging system behavior is extremely important towards our goal of designing reliable high-performance audio systems. The charging system must be carefully considered when choosing the amount of amplifier power to use as we design these systems. In this section, we will cover charging system fundamentals for both automobiles and marine vessels. Many of these areas have some overlap and many of the same rules apply, but we will make distinctions when necessary. One key distinction is that some vessels will have something other than a 12-volt charging system. While this is also true of some vehicles, it is far more likely to happen on vessels than in vehicles. In addition to having a DC-based electrical system, many larger vessels will also have an AC-based system. These dual systems are a bit outside the scope of this presentation, but it is worth mentioning that there are certain issues that can occur when working on these vessels and if you are interested to learn more, you can find information from the American Boat and Yacht Council (ABYC), the National Marine Electronics Association (NMEA) or the International Marine Electronics Alliance (IMEA).

A typical charging system consists of the following elements:

1) An Alternator
2) A Voltage regulator
3) A Battery (or batteries)
4) Wiring







The Alternator

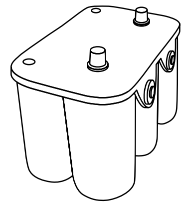
Purpose of an alternator:
Provides the voltage to operate the vehicle's electrical systems while the engine is running and to recharge the battery.

How an alternator works:
An alternator is an AC generator with diode rectification to convert AC (alternating current) into pulsing DC (direct current). Inside an alternator you will find a rotating electromagnet (called a rotor) inside a stationary ring (stator) that supports three windings. It produces AC current via electromagnetic induction in the stator. In simpler terms, the magnetic field of the rotating electromagnet induces current in the stator's windings. The diodes on the output of the stator's windings rectify the AC current, which means they convert it to pulsing DC. A portion of the current is fed back to the field windings to increase alternator output. It should be noted that the output of an alternator is only available when the rotor is moving which implies that the engine is running. While this is often the case in a traditional mobile application, it is not always the case in marine applications. This is certainly something to keep in mind.

Special note about alternator whine:
The whining noise we often encounter in many audio systems is caused by the fact that the alternator's DC output is pulsing, which creates a "ripple" in the charging voltage. This ripple can imitate an AC audio signal that varies in frequency with engine RPM if it gets into our audio signal path. In fact, most of the odd noises we encounter (pops, ticks, buzzes, etc…) will be the result of some 'ripple' or other electrical impulse that finds its way into the audio path.

The Voltage Regulator

Purpose of a Voltage Regulator:
Controls the current in the field windings to vary alternator output depending upon the battery voltage. This is to prevent under or over-charging of the battery (or batteries). In some alternators, the voltage regulator is an external, stand-alone device while in others it is built in.



The Battery

A battery does three things:

a) Provides the initial power to start the engine and drives all DC-based electrical accessories when the engine(s) are off.
b) Provides additional energy to the electrical system when demand exceeds alternator output.
c) Acts as a buffer to smooth out voltage surges, voltage spikes and to stabilize electrical system charging voltage while the engine(s) are running.

How the battery does it:
The battery stores energy in chemical form. When needed, the battery produces a chemical reaction that releases a large amount of electrical current (DC) at a sustained voltage for a specified period of time and attempts to sustain current flow as long as there is demand. When demand ceases, the chemical reaction gradually slows down and the battery reaches a calm state, called "rest". If the discharge cycle is repeated enough times without sufficient recharging, the battery will become completely discharged (dead). A battery will only recharge when the alternator's output voltage exceeds the battery voltage. When in this condition, the battery is a load on the alternator, not a relief or buffer.

What kind of electrical output does a battery produce?
A 12V mobile or marine battery outputs DC current at a DC voltage level. As the battery becomes discharged, its DC voltage decreases.

What is inside a battery?
Inside a 12V car battery, you will find six individual "cells". Each cell produces 2.1 (DC) volts. The six cells are connected in series inside the battery, which adds their voltages together for a total of 12.6 volts (DC).

Special note about batteries:
In most marine applications, the amount of "engine off" use of various electronics is typically much greater than you will find in automotive applications. This will usually lead to a battery being more depleted before the alternator is active again (when the engine(s) are running again). This deep state of discharge followed by active recharging is known as 'deep cycling' the battery(s). There are several batteries available that are intended for these conditions, and these are logical choices in any application where the electronics will draw from the battery(s) for extended periods of time before being recharged.

The Wiring

Purpose of the wiring:

To conduct electrical current from the alternator to the electrical systems and to the battery, for recharging. In many modern mobile and marine applications, it is unlikely that these can be modified easily.

The importance of wire gauge:

Thicker wires have less resistance than thinner wires and are necessary to pass large demands of DC current without voltage drop. Similarly, if the wire length is long, you may need to increase the gauge (thickness) of the wire to reduce voltage drops. This is particularly true in marine applications (See side bar).

What about the charging system on an electric vehicle?

In general, most EV electrical systems are going to follow a similar layout. The main high voltage battery that is used for the motor(s) will replenish power to the lower voltage system (usually 12–16-volt systems with possible 48-volt systems imminent) through a power inverter that is controlled by the computer. The computer monitors the current draw and if the current exceeds certain values, the computer can limit or shut down circuits to prevent short circuits or overloads. When adding an aftermarket audio system, care has to be taken to ensure that the additional current draw can be supported and will not exceed limitations of the vehicle.

How much current does the car / vessel need?

In any application, there is a certain amount of electrical energy that is needed to make the car or boat actually function and offer the operator certain controls and comforts. Since we are attempting to add additional benefits by installing a high-performance audio system, we need to make sure we are not using too much of the available energy. Failure to consider the needs of the application could quickly lead to failures either with the new audio system or with some critical functions of the vehicle / vessel.

Even without knowing the specific amount of current draw for a given application, there are some generalizations that can be made. Systems with small to modest electrical systems are unlikely going to be able to handle kilowatts of additional amplifiers without some negative results. As the electrical systems become more capable, you may be able to add some additional power without too much concern.

A special note about wiring in marine applications:

The wiring on a vessel is also a bit different than you will find in a typical automobile. In a vehicle it is common practice to use the metal chassis of the vehicle as a 'return path' for electronic devices. This allows you to run one wire from the positive post of the battery to the device and connect the other (negative) terminal from the device to the metal chassis. The battery negative post is also connected to the chassis, so you don't need the other wire, just use the metal that is already there. Since most marine hulls are non-conductive, this is not possible in marine applications. This leads to some additional considerations when adding electronics on a vessel.

Another critical consideration for choosing the right battery, is cranking amps. Cranking amps are usually referred to as CCA (cold cranking amps) in automotive applications or MCA (marine cranking amps) in marine applications. MCA is essentially the same as CCA except MCA is specified at a slightly different (higher) temperature. Cranking amps are useful for short duration electrical needs such as starting engines. A battery with higher cranking amps will be able to start engine(s) easier than one with lower cranking amps.

The specification of reserve capacity also becomes very important in marine applications when we are more likely to use the DC-based electronics with the engine(s) off (drifting, swimming, sand bar BBQ, etc…). The reserve capacity of a battery is the number of minutes that a fully charged battery at 80 degrees (Fahrenheit) is discharged at the vehicle/vessel's stock current draw before the battery drops to 10.5 volts (in a 12-volt system – approximately a 15% drop). With nothing added to a typical vessel, the reserve capacity is how much engine off time can pass with the electronics and accessories powered on without much concern about being able to start the vehicle/vessel again (assuming a single battery bank). Remember, this is before we add audio and other aftermarket accessories. When we add amplifiers and source units, it becomes increasingly important to anticipate the current demands and scale up the reserve capacity accordingly. How much reserve capacity will be determined by several factors including: how much power is being used (how many watts), the type of amplifier (amplifier efficiency), the application (subwoofer or main speakers, etc…) and the type of listener.

How much additional alternator current is available?

It is important to have an idea of how much current the DC-based electronics are likely to draw. Listed below are typical current draws for both mobile and marine systems for common electronic devices. Keep in mind that turning on additional DC-based accessories will increase current draw further.

CAR	MARINE
Instrument Panel: 1.5 amps	16-inch GPS / MFD: 3-5 amps
Ignition: 5-10 amps	CHIRP Echo Sonar: 5 amps
Electric Fuel Pump: 4-6 amps	Autopilot (active / standby): 3 amps
Electric Cooling Fan: 8-12 amps	Autopilot (engaged): 30 amps
Incandescent Lights (with headlights on): 20-30 amps	Radar: 10-12 amps
LED Lights (with headlights on): 5-10 amps	VHF (Standby): 1.5 amps
Air Conditioner: 15-25 amps	VHF (TX Lo-power): 1.5 amps
Source Unit (non-amplified): 5-10 amps	VHF (TX Hi-Power): 6 amps
Seat Heaters: 15-20 amps	
Electric Power Steering: 10-15 amps	
Power Control Module: 10-20 amps	

In general, automotive and marine manufacturers traditionally will not put much more alternator and battery capacity in a vehicle/vessel than the standard accessories will need. Bigger charging systems cost money and impact fuel economy so it is in their interests not to provide a big safety margin. Many modern vehicles will turn off the alternator field (or the engine that drives them) to conserve fuel while the vehicle is stopped. For this reason, we must be careful in matching aftermarket audio power to the vehicle/vessel's charging system (unless we're willing to upgrade the charging system when possible).

Focusing on vehicles for a moment, beginning around the year 2000, stock electrical systems began to change. Even compact and mid-sized vehicles are now coming with more robust alternators and charging systems. On the surface, these changes may seem to offer the aftermarket some additional freedom. In reality, the reason for the upgrades is related to the increase in demand from modern factory electronics (electronic-assisted power steering, damping control and brakes, temperature-controlled seats, sport modes, cameras, adaptive cruise control, autopilots and other driver safety features, etc... Along with old mainstays such as cruise control, air conditioning, power windows and traction control; now standard on many vehicles). For example, the 90's Civic that had a 65-amp alternator, and a 45-60-amp current draw now has a 130-amp alternator with up to a 125-amp current draw. Even though the electrical system has doubled in size, there isn't more room to grow the aftermarket current draw, and in some cases, there is even less room. Even large SUVs like the Chevrolet Tahoe may have standard 150-amp alternators with options taking them even higher. Unless it is the base model, the Ford Explorer may have a 200-amp alternator but again dissecting the rest of the electrical system, it only allows 10-20 amps to play with. Hybrid and electric cars pose another consideration with customers having to accept a minor decrease in range due to the additional load on the electrical system. However, since we are tapping into the '12-volt aspect of these vehicles, the load we are adding is in the regenerative charging and the draw from the high voltage batteries, this is only a small percentage. Consider that on a Tesla, the heater on the high setting consumes about 6.4 kWh (Kilowatt hours) which will decrease range by about 18-20 miles for each hour it is on. Even with a 1,000-watt amplifier, you are looking at losing only about 1/10th that amount (1.5-2 miles of range lost per hour of jamming out). Even though we may seem to have a more robust charging system to start off with, what we need to focus on is the remaining available current (or acceptable loss of range) for each vehicle that we work with.

Typical alternator outputs:

Compact 4-cyl. vehicle: **80-130 amps**
Mid-Size 6-cyl. vehicle: **100-160 amps**
Large 8-cyl vehicle: **140-240 amps**

It is important to note that alternators specifications often give two ratings: "cold" and "hot". Alternators are typically rated cold, (the SAE rating). When the alternator heats up, there is a considerable loss of output. Whenever both cold and hot ratings are stated, use the hot rating. If no distinction is made between hot and cold, assume the rating is cold and multiply it by 0.85 to get a rough approximation of the hot rating.

A compact car, like a Honda Civic, will typically have a 130 Amp alternator. Some of that current will be lost once the alternator gets hot, (about 15%) which would result in about 110 amps available. It is likely that with the lights on and A/C off there will likely be around a 60-70-amp draw. With the A/C on, it will likely be an 80-90-amp draw. Keeping the above in mind, we have about 20 amps of available current in this car. This is not a lot to work with.

Now let's look at a mid-sized 6-cylinder car with a 150 Amp alternator. After the loss from heat, there will be around 125 amps available. With the lights on and A/C off, there will likely be around a 70-80-amp draw. With the A/C on, it will likely be 90-100-amp draw. This will leave around 25-30 amps available. That is a bit better.

A large 8-cylinder car or SUV with a 180 Amp alternator will lose about 30 amps to heat which would leave about 150 amps available. The average draw of about 70-80 amps with lights and A/C off, 80-100 Amps with the A/C on. This will leave about 50 amps of available current in this vehicle. Now we have some juice!

All of this of course begs the question: "How much amplifier power can we safely and reliably stuff into a vehicle/vessel?" To answer this, we must ask a few more questions.

How much current do amplifiers draw in the real world?

This is not a simple question to answer. Most customers will vary their listening levels over the course of their travel. At times, they may crank the system up to 50% average power level (clipping the daylights out of their amplifiers). Some of the time they may just play it "pretty loud" (10% average power) and for some portion of the time they will play the system at a moderate average level (1-2% average power). During loud passages in music, amplifiers can draw quite a bit of current, but they also draw substantially less during quieter passages. This is why it is useful to look at the average current draw for amplifier(s) in a sound system.

Rule of Thumb for Predicting Real-World Amplifier Current Draw:

Disclaimer: The only way to reliably know the current draw is to measure it with an inductive clamp and an ammeter and average it over time. Predicting audio system current draw is very difficult because we must consider that different listeners have different habits and the same listener's habit can vary. Additionally, charging system voltage has an impact on current draw, especially when using amplifiers with regulated power supplies. The type of music being played also has an impact. Because it is so complex to figure this out, we need a simpler method to guide us in choosing amplifier power when designing a sound system. The following is a general guideline, which makes some broad assumptions but is useful for system design purposes. It is not intended to precisely predict actual current draw, but rather serve as a "rule of thumb" when designing a system. We are going to assume that the average amplifier power output for a typical listener over the course of a drive will be 20% of the amplifiers continuous power rating. This assumes that the user might crank it excessively loud for a few minutes, might listen to it quietly for a while but will listen at loud levels, most of the time. If the listener is more likely to crank it excessively, most of the time (closer to 50% of the amplifiers continuous power rating), you should consider scaling back the amount of power used. Similarly, if the listener is more of an audiophile and not likely to play the system very hard for very long (closer to 10% of the amplifiers continuous power rating), you might consider a bit more amplifier power.

To calculate real-world amplifier current draw, use the following steps:

1) Take the amplifier's continuous power rating and multiply it by 0.2 (20% of its power rating). As noted above, this is the average amount of power that the amplifier is likely to produce during a typical drive.
2) In order to account for amplifier efficiency and duty cycle, follow these guidelines:
   a) For a Class A/B amplifier driving main speakers, use a factor of 2.0
   b) For a Class A/B amplifier driving subwoofers, use a factor of 3.0
   c) For a Class D amplifier driving main speakers, use a factor of 1.5
   d) For a Class D amplifier driving subwoofers, use a factor of 2.0
3) Take the number from Step 2 and divide it by the nominal charging system voltage. The result will be the predicted average current draw for this amplifier. If you are using multiple amplifiers, you should calculate each one independently and add up the values for the total system current draw.

Notice: When determining the power rating in Step one, the 12.5-volt rating (not 14.4 volts) should be used and the power at the expected impedance load for the amplifier. If the amplifier is only rated at 14.4 volts you can approximate the 12.5 rating by multiplying the listed power by 0.75. For example, if the amplifier is rated for 1,000 watts at 14.4 volts, it will deliver about 750 watts at 12.5 volts. In marine, it is quite common to use an 11-volt value, but since most amplifiers are rated at 12.5 or 14.4 volts, we will stick with 12.5 volts for marine examples as well.

AMP MODEL	AMP TYPE	FUSE	EXPECTED CURRENT
MX300/1	Mono Amp	30	4 - 20 Amps
MX280/4	Multi-Channel	35	3 - 17 Amps
MX500/1	Mono Amp	50	6 - 32 Amps
MX500/4	Multi-Channel	50	5 - 29 Amps
MX600/3	System Amp	60	9 - 32 Amps
JD250/1	Mono Amp	30	4 - 16 Amps
JD500/1	Mono Amp	50	7 - 32 Amps
JD1000/1	Mono Amp	80	16 - 64 Amps
JD400/4	Multi-Channel	40	6 - 29 Amps
RD400/4	Multi-Channel	40	6 - 29 Amps
RD500/1	Mono Amp	50	7 - 32 Amps
RD1000/1	Mono Amp	80	16 - 64 Amps
RD1500/1	Mono Amp	150	24 - 120 Amps
RD900/5	System Amp	60	12 - 50 Amps
XDM200/2	Multi-Channel	20	3 - 14 Amps
XDM400/4	Multi-Channel	40	6 - 29 Amps
XDM600/6	Multi-Channel	50	9 - 43 Amps
XDM800/8	Multi-Channel	60	12 - 58 Amps
XDM300/1	Mono Amp	30	5 - 22 Amps
XDM600/1	Mono Amp	50	10 - 40 Amps
XDM1000/1	Mono Amp	80	16 - 64 Amps
XDM500/3	System Amp	50	9 - 32 Amps
XDM700/5	System Amp	60	12 - 46 Amps
XDM1000/5	System Amp	80	15 - 62 Amps
VX600/2i / MV600/2i	Multi-Channel	50	7 - 36 Amps
VX400/4i / MV400/4i	Multi-Channel	40	6 - 29 Amps
VX600/6i / MV600/6i	Multi-Channel	60	9 - 43 Amps
VX800/8i / MV800/8i	Multi-Channel	60	12 - 58 Amps
VX600/1i / MV600/1	Mono Amp	50	10 - 40 Amps
VX1000/1i / MV1000/1	Mono Amp	80	16 - 64 Amps
VX700/5i / MV700/5i	System Amp	60	12 - 46 Amps
VX1000/5i / MV1000/5i	System Amp	80	15 - 62 Amps
HD600/4 / MHD600/4	Multi-Channel	50	14 - 48 Amps
HD750/1 / MHD750/1	Mono Amp	60	18 - 60 Amps
HD1200/1	Mono Amp	100	38 - 96 Amps
HD900/5 / MHD900/5	System Amp	60	26 - 64 Amps

Examples:

Example 1: A full range class D amplifier used for main speakers.
The amplifier is rated to deliver 140 watts per channel at 12.5-volts into two 4-ohm speakers (stereo).

1) 280 watts (140 watts/ channel, two channels) * 0.2 = 56
2) 56 * 1.5 = 84
3) 84 / 12.5 = 6.72 The typical nominal charging system voltage is 12.5 volts. The answer "6.72" can be rounded to 7 amps.

Example 2: A full range class D amplifier used as a subwoofer amplifier.
The amplifier is rated to deliver 450 watts at 12.5-volts into a single 4-ohm load (bridged).

1) 450 * 0.2 = 90
2) 90 * 2 = 180
3) 180 / 12.5 = 14.4 The typical nominal charging system voltage is 12.5 volts. The result, 14.4 amps can be rounded to 15 amps.

Example 3: A full range Class D used as a system amplifier (five-channels).
The four main channels of the amplifier are rated to deliver 60 watts each into 4-ohm speakers. The mono channel is rated to deliver 180 watts at 12.5-volts into a 4-ohm subwoofer.

1) (4 * 60) = 240 * 0.2 = 48
2) 48 * 1.5 = 72
3) 72 / 12.5 = 5.76 (round up to 6 amps)

Subwoofer channel:

1) 180 * 0.2 = 36
2) 36 * 2 = 72
   Even though this is a Class D amplifier, low frequencies require a lot more from an amplifier, so we should use the higher value to adjust for the duty cycle of this application.
3) 72 / 12.5 = 5.76 (round up to 6 amps)

In this application, our 5-channel system amplifier will have an average current draw of about 12 amps.

If we were to use a 2-ohm subwoofer, and this amplifier is rated to deliver 300 watts into 2 ohms, here is how things would change:

1) 300 * 0.2 = 60
2) 60 * 2 = 120
3) 120 / 12.5 = 9.6 amps (round up to 10 amps)

So, we would be looking at about 16 amps total, average current draw instead.

Example 4: A full range class D amplifier powering three pairs of 4-ohm speakers (six-channels).
The amplifier is rated to deliver 75 watts per channel into 4-ohm speakers at 12.5 volts.

1) 450 * 0.2 = 90
2) 90 * 1.5 = 135
3) 135 / 12.5 = 10.8 amps (round up to 11 amps)

If we use that same amplifier in the same application but with a more abusive listener, we can see how a 'heavy handed listener' impacts the system:

Example 5: A full range class D amplifier powering three pairs of 4-ohm speakers (six-channels) with a 'heavy handed listener'.
The amplifier is rated to deliver 75 watts per channel into 4-ohm speakers at 12.5 volts.

1) 450 * 0.5 = 225
2) 225 * 1.5 = 337.5
3) 337.5 / 12.5 = 27 amps

The heavy-handed listener using the same set up is likely to draw more than twice the current. It is important to note that the expected average current draw is not the value used to determine proper fusing. This value is only useful when determining reserve capacity needs.

Example 6: A class D amplifier powering a subwoofer.
The amplifier is rated to deliver 600 watts into a 2-ohm load at 12.5 volts.

1) 600 * 0.20 = 120
2) 120 * 2.0 = 240
3) 200 / 12.5 = 25 amps

You will notice that we use an efficiency factor of 2.0 in Step Two to account for the Class D amplifier being used to power a subwoofer system. If we look at the results of Example 4 and Example 6, we can see in a common system, these two amplifiers used together will draw about 36 amps of current on average. If the listener is more 'heavy handed', that value can be well over 50 amps using the same two amplifiers. Plan wisely.

You can use this general guideline to predict the current draw for any amplifier you are considering for system design.

Now that we can predict likely current draw, let's go back to our examples:

In an application where we have between 5-20 amps of available current, what can we recommend? A great option may be a low power, three or five-channel amplifier. Example three would result in between 12 and 16 amps of current which would fit nicely in an application like this. Since we are limited in the amount of amplifier power we can reliably install, if the customer is looking for a lot of output (without upgrading the electrical system), we will have to achieve it by enhancing the speaker system efficiency (larger speakers or multiple smaller speakers).

In an application where we have between 20-30 amps of available current, we could consider a more powerful five-channel amplifier or maybe several amplifiers instead. Example 2 and Example 4 would give us a subwoofer amplifier at 450 watts and a six-channel amplifier at 75 watts per channel and we would end up with about 26 amps of additional current draw. If the user is a 'heavy handed listener', consider upgrading the electrical system or sticking with the 5 lower power five-channel option.

In an application where we have between 40-50 amps of available current, we have some extra capability. Everything mentioned above would work, or some of it could be doubled! Although, if the desire is to add multiple kilowatts, an upgrade to the electrical system would still be required.

Charging System Upgrades:

The following are some basic guidelines to follow regarding different types of charging system upgrades. The two tools you must have to properly diagnose and troubleshoot charging systems are a good quality DMM (digital multi-meter), and an inductive current clamp to measure current draw. Every shop should have these tools.

Upgrade 1: The Magic Wires (car audio)

Replace the factory ground strap (wire) between the battery and the car chassis (body) with at least a 4-gauge cable. This will help minimize voltage drops caused by high resistance in the stock cable. Also replace the stock charging wire between the battery and the alternator with at least a 4-gauge cable. If the alternator has a chassis ground cable, upgrade that wire too.

This is relatively inexpensive and should be done for every system 500 watts or higher in total amplifier power. A case could be made that upgrading the wiring in a vessel would be beneficial as well, however it is usually much more complicated and costly.

Upgrade 2: More Powerful Alternator

There is simply no substitute for a large supply of current. Batteries and capacitors don't produce anything; they are merely storage tanks. When an engine is running, the alternator delivers the vast majority of the current demanded by the electronics and audio system. For this reason, alternator upgrades make a lot of sense for powerful audio systems. This is not an inexpensive upgrade but should be considered before any of the following if the electrical system is having problems supplying adequate current. It is often possible to purchase a more powerful alternator for about the same price as a couple of capacitors, an additional battery and all the wiring needed to connect them, but the alternator will actually work.

Here is a handy chart that can make this process a bit easier. It shows the average expected current draw based on 100 watts of power.

	Class D Full Normal	Class D Sub Normal	Class AB Full Normal	Class AB Sub Normal	Class D Full Excessive	Class D Sub Excessive	Class AB Full Excessive	Class AB Sub Excessive
Per 100 Watts	2.4	3.2	3.2	4.8	6	8	8	12

Upgrade 3: Capacitors

A capacitor helps to maintain voltage during very brief peaks in demand. They can be particularly useful in sound quality-oriented systems with moderate power. Unregulated amplifiers will benefit more than regulated amplifiers. However, they won't be very beneficial while playing intense bass music at high volumes. Capacitors simply cannot supplement current and voltage for very long. Capacitors can typically charge and discharge faster than most standard, lead acid or AGM battery types which makes them very effective for sound systems.

Upgrade 4: Multiple Batteries

Multiple batteries are helpful for engine(s) off listening but are an additional load for the alternator to supply current to once the engine(s) are running. Multiple batteries are not recommended for everyday mobile sound systems although some demo and competition cars may benefit from using them. There may be some applications in vehicles where the vehicle shuts down the engine(s) or alternator field to improve fuel consumption, where multiple batteries may be beneficial.

Some marine vessels may only have one battery or possibly specific battery banks isolated for certain electronics/motor(s). If the additional power demand from the audio system is going to add significant stress on the battery(s) it may be worth considering adding a dedicated (separate) battery or battery bank. This would allow the user to use the accessories on the boat without risking a depleted battery in the event of an emergency or when it is time to start up the engines again and head back to shore.

Since most vessels do not (or cannot) use the hull as part of the electrical system, all electrical components will need both a primary and return wire connected to and from the battery bank(s). This makes the effective length of the power run twice what might be expected in a mobile application (where the chassis is often used as the return path). There are many charts that are available to help make good choices on what size (AWG) wire to use. These charts are all based upon Ohm's law. Even a very thick wire will have resistance (usually measured in 'Ohms per foot' or something similar) and even a very low resistance value over a long run will lead to an unacceptable voltage drop across the length of the run.

Voltage Drop:

Ohm's Law says that for a given amount of current, higher resistance will lead to a voltage drop (E = I x R) in that part of the circuit. As resistance or current goes up, the value for E (voltage) will go higher, meaning that you are reducing the potential. The marine industry has established that voltage drops of 3% or lower (less of a drop) is considered acceptable. For a 12.5-volt system, that works out to be a voltage drop of about 0.375 volts.

Example: If our vessel has an audio system that is rated to draw about 75 amps of current and the battery is 10 feet away, we should look at the column for "16-20 feet" (10 feet to the amps from the battery, 10 feet back from the amps to the battery) and the row for '60-80A'. The chart below indicates that a 4AWG wire should be sufficient. If you wanted to check that against Ohm's Law and the acceptable voltage drop you would need to determine the 'Ohms per foot' for the 4AWG wire (approximately 0.00025 Ohms). If you take that value multiplied by the total length; 0.00025 x 20 = 0.005 Ohms. This number looks incredibly small but when we apply Ohm's Law with 75 amps of current:

E = I x R
E = 75 x 0.005
E = 0.375 Volts

Ohm's Law states:

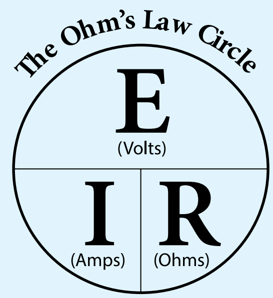
Voltage (E) = Current (I) x Resistance (R)

Using simple algebra, we can twist the basic formula around to solve for current or resistance as follows:

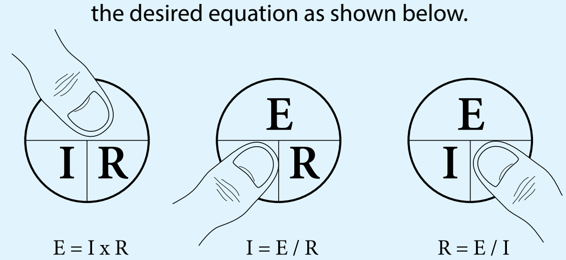
Current (I) = Voltage (E) / Resistance (R)

Resistance (R) = Voltage (E) / Current (I)

A simple and easy tool to help remember and use this law is the *"Ohm's Law Circle"*.



To find the equations you need, place a thumb over the variable you wish to find. The remaining two letters form the desired equation as shown below.



	0-3 ft.	3-6 ft.	6-10 ft.	10-13 ft.	13-16 ft.	16-20 ft.	20-25 ft.
0-20 A	10 AWG	10 AWG	10 AWG	10 AWG	10 AWG	10 AWG	10 AWG
20-40 A	10 AWG	10 AWG	8 AWG	8 AWG	8 AWG	8 AWG	8 AWG
40-60 A	10 AWG	8 AWG	8 AWG	8 AWG	4 AWG	4 AWG	4 AWG
60-80 A	8 AWG	8 AWG	8 AWG	4 AWG	4 AWG	4 AWG	4 AWG
80-100 A	8 AWG	8 AWG	4 AWG	4 AWG	4 AWG	4 AWG	4 AWG
100-125 A	8 AWG	8 AWG	4 AWG	4 AWG	4 AWG	4 AWG	2 AWG
125-150 A	8 AWG	4 AWG	4 AWG	4 AWG	2 AWG	2 AWG	2 AWG
150-200 A	4 AWG	4 AWG	4 AWG	2 AWG	2 AWG	1/0 AWG	1/0 AWG
200-250 A	4 AWG	4 AWG	2 AWG	2 AWG	1/0 AWG	1/0 AWG	1/0 AWG
250-300 A	4 AWG	2 AWG	1/0 AWG	1/0 AWG	1/0 AWG	1/0 AWG	2/0 AWG

As noted above, 0.375 volts is the same as a 3% drop on a 12.5-volt system. These values also apply to mobile audio as well. Powerful, high current amplifiers will require large amounts of current. In many vehicles, the chassis can be limited in its ability to pass current, and many will need an additional ground added as an augmented ground. This is where a ground wire from the battery is routed to the ground point where the audio amplifiers are connected to and lowers resistance to ground for all circuits nearby. This will not only improve the performance of the audio system, but also any other electronic devices nearby will also reap the benefits.

An important thing to remember is that the charts that are common to find for recommended wire gauge compared to length and current will be rounded off to the nearest, readily available power wire gauge. In this case, if our system were rated for 80 amps, that same length of wire would lead to a 0.4 volt drop which, technically, is too high. A 3 AWG wire would only have a resistance of 0.0002 ohms per foot resulting in a total resistance of 0.004 Ohms and a corresponding voltage drop of 0.32 volts (below the 3% threshold). Unfortunately, 3 AWG wire is incredibly rare so it would not make much sense to show that in a chart. When in doubt, go with a thicker wire (lower AWG number).

For the same reason that large subwoofers are impractical in small spaces (they don't fit), powerful amplifiers are impractical in some applications (too much current). Knowing what the limits are, can allow us to design and install systems that perform better and are more reliable.

Module 6: Power Distribution Between Subwoofers and Satellites

As we have learned, real instruments produce complex sounds that cover a wide frequency range. Big drums and bass guitars, for example, produce fundamentals that are centered in the sub-bass range and harmonics that extend way into the mid-range frequencies. Because of this, for a sound system to accurately reproduce the tonal character of low frequency instruments, we must have balance between sub-bass / mid-bass / mid- range and high frequencies.

Unfortunately, many people place a disproportionate emphasis on the subwoofer end of the spectrum (the bottom two octaves from 20 – 80 Hz), purchasing big power and big woofers to achieve lots of bass energy. Then they spend too little on improving the power to the satellite speakers (mid-bass, mid- range, high frequencies) and the quality of those speakers. The satellites are charged with reproducing eight of the ten audible octaves (from 80 Hz – 20,000 Hz). If the satellite system runs out of power, not only will the mid-bass, mid-range and high frequencies sound distorted but the bass will not sound right either. The harmonics necessary to give low-frequency instruments their character will simply not be there in the correct proportions.

To properly reproduce music, we should generally strive for subwoofer power / satellite power ratios between 60 / 40 and 70 / 30.

The lower the overall system power, the closer to 50 / 50 you should try to stay. Satellite speakers need plenty of clean power because distortion is far more audible in the mid and high frequencies than in the sub-bass. This fact allows us to clip the subwoofer amplifier quite a bit without degrading sound quality while avoiding excessive clipping of the satellite amplifier.

Below 500 watts try to stay close to 50 / 50 and no more than 60 / 40.

Above 500 watts total you can swing the ratio towards 70/30.

To calculate the ratio, take each amplifiers output and divide by the total amount of watts in the system, then multiply by 100. For example, a VX600/6i at 12.5 volts puts out 60 watts x 6 so 360 watts total and the VX600/1i produces 500 watts at 12.5 volts. Together these amplifiers produce 860 watts. Now that we have the power we can calculate the ratio.

360 / (360 * 500) = 360 / 860 = 0.42 we then multiply that by 100 to get the VX600/6i is 42%
500 / (360 * 500) = 500 / 860 = 0.58 we again multiply by 100 to get the VX600/1i is 58%

Here are some examples of good matchups using JL AUDIO amplifiers:

JD250/1 and JD400/4D (220 watts / 220 watts – 440 watts total) Power Ratio: 50 / 50
RD500/1 and RD400/4 (400 watts / 240 watts – 640 watts total) Power Ratio: 62 / 38
XDM600/1 and XDM400/4 (240 watts / 300 watts – 540 watts total) Power Ratio: 55 / 44
XDM300/1 and XDM200/2 (120 watts / 160 watts – 280 watts total) Power Ratio: 57 / 43
XDM500/3 (160 watts / 120 watts – 280 watts total) Power Ratio: 57 / 43
VX700/5i (300 watts / 240 watts – 540 watts total) Power Ratio: 55 / 45
HD750/1 and HD600/4 (750 watts / 600 watts – 1350 watts total) Power Ratio: 55/ 45
VX1000/1i and VX800/8i (800 watts / 480 watts – 1200 watts total) Power Ratio: 62 / 38

Here are some examples of bad / questionable matchups using JL AUDIO amplifiers:

HD1200/1 and factory radio (1200 watts / 40 watts – 1240 watts total) Power Ratio: 97 / 3
HD750/1 and factory radio (750 watts / 40 watts – 790 watts total) Power Ratio: 95 / 5
HD1200/1 and XDM200/2 (1200 watts / 120 watts – 1320 watts total) Power Ratio: 91 / 9
HD1200/1 and XDM400/4 (1200 watts / 240 watts – 1440 watts total) Power Ratio: 83 / 17

Module 7: System Level Setting Tips

As systems become more complicated, setting levels can also be a bit more complicated. Proper level setting through the audio path can make or break the performance and reliability of a system, so getting it right is obviously important. There is an old saying that goes something like: "Gain up as early as possible". What this means is that you want to start with a good, clean, strong signal as close to the audio source as possible. With every electric device you add to the path, you increase the likelihood of noise entering the audio. This noise can be related to grounding issues ("whine" noises) and system noise ("hiss" noises). Grounding noises will always be related to electrical connections while system noises will be related to level settings.

In a traditional system, you can see how the 'gain up early' mantra comes in to play pretty easily. On your amplifier there is an input sensitivity adjustment (often erroneously referred to as a "gain" control). As the proper name implies, this adjustment determines how sensitive the input stage of the amplifier is to the signal (voltage) that is coming in to the amplifier. Making it more sensitive (turning it up) means increasing the ratio between the input voltage and the output voltage; less input voltage is required to get the amplifier to produce a given amount of power. Since the amplifier is not able to distinguish between what is music and what is noise, increasing the sensitivity can also have the negative impact of increasing the audibility of noise in the system. In an ideal setup, the amplifier would be reaching maximum potential at the same time that the source unit is reaching full volume. This is often done by sending a sine wave from the source unit to the amplifier and viewing it on an oscilloscope to see when the wave form is clipped. A meter that can detect distortion (which is indicative of a clipped sine wave) can also be used. If you have a higher voltage audio signal, you can keep the input sensitivity set lower and greatly improve system noise without compromising output.

In reality, if we were to set up an audio system to only reach 'full, unclipped output" at full volume, most people would be disappointed at the overall level of their system. Knowing that music and sine waves are very different, and that people have certain expectations, let's take a look at some methods to setting levels.

Proper level setting actually starts with the source unit itself. If you want to make sure that everything is as 'clean' (undistorted) as possible, you should use a sine wave and an oscilloscope (or distortion meter) to see at what level the source unit runs into clipping, if ever. While it is helpful to know what that voltage is, it is arguably less important than knowing the position of the volume control. If you can go all the way up, then you can rest easily that the signal will be clean to the next device in the audio path. If, however, clipping occurs, it is helpful to know when that happens. For example, if the source unit has a numeric readout that shows "100" when it is at full volume and "0" when it is turned all the way down, and the wave form is clipped at "80", then you will want to set your levels at or slightly below that position (maybe "75") on the source unit. Otherwise, your other measurements will be affected by the clipping from the initial source.

If you are lucky enough to have a source unit that does not clip, you have some freedom as to where you may want to set the main volume control before setting the levels on the rest of the equipment. A good practice may be to use 75% of maximum volume. This allows for the user to turn the system up a bit more and allow some amount of clipping. Remember, sine waves and music are very different and even very demanding music is unlikely to send more voltage than a sine wave, or at least not as often. A little bit of clipping is not only considered "ok", it is often desirable in order to keep the audio levels where people will be happy.

With any processor that does not have regular adjustments (no volume or sub level controls, etc…), you can be a bit more particular on how you set levels. Set your source to your preferred "reference point" (IE: 75% of maximum), turn the input level adjustment and the output adjustments to their "middle" position ("0dB" or "reference", etc…), then measure the sine wave to ensure that it is still unclipped. If it is clipped, turn down the input level until it is not clipped. If it is not clipped you **might consider** turning it up until just before clipping. Then turn your attention to the output level and start increasing it until just before the waveform clips. Repeat this procedure for every single processor in the path. Set the input to the lowest position before clipping and the output to the highest position before clipping.

When set this way, the results will be:

1) All processors will reach their maximum, unclipped potential together.
2) System noise (hiss) will be minimized
3) You have the ability to slightly overdrive the system without audible problems.

Fortunately, most processors will have indicators that will show when the signal is reaching the limits. This can allow you to set levels making just a few assumptions.

Most source units will not clip at 75% of maximum level (assumption #1). Most quality audio gear all have indicators that are generally accurate as to when they are reaching maximum levels (assumption #2). Most people will not be happy with an unclipped audio signal throughout the entire audio path (assumption #3), it tends to sound quieter than most would expect.

If you are comfortable with those assumptions, the new procedure looks like this:

1) Set source volume position to 75% of maximum
2) Turn all input adjustments to the highest position before clipping (using the lights as your guide)
3) Turn up the output adjustments to the highest position before clipping (using the lights as your guide)

Using either procedure, if you find the system noise (hiss) is objectionable, you can lower the input level of each processor and revisit the output adjustments each step of the way. If you still have objectionable hiss, you may be dealing with a noisy processor.

This concept can continue all the way through to the amplifier. Of course, many amplifiers will not have lights indicating when they are at their maximum (input or output), so we either have to break out the oscilloscope, or find another way. Fortunately, there is another way, but again, you have to be comfortable with assumptions. In addition to the assumptions mentioned already, assumption #4 is that a speakers nominal impedance is close enough for using the power equation, in this case: Power = Voltage squared divided by Resistance ("nominal impedance").

There is a bit of math involved, but it is not too bad. The way this method works goes back to Ohm's Law (voltage squared divided by resistance). Now, technically resistance refers to elements in a DC (direct current) circuit and when we are working with audio signals, we are dealing with AC (alternating current). This is not an insignificant difference, of course, but for our purposes, we can ignore the difference and use the formula in a slightly different form (Voltage is equal to the square root of power times resistance) to find a voltage that would be equal to the power rating of an amplifier. An example should help show this.

Example:

We have an amplifier that is rated to deliver 600 watts into a 2 Ohm load. Using our formula, we find:

$$\text{Voltage} = \sqrt{(\text{Power}*\text{Resistance})}$$
$$\text{Voltage} = \sqrt{(600*2)}$$
$$\text{Voltage} = \sqrt{(1200)}$$
$$\text{Voltage} = 34.64$$

OK, so we have a target now. If you were to disconnect your speaker wires and send a clean sine wave into our amplifier as described above, you can set the input sensitivity until we see, in this example, 34.6 volts (AC) on our meter on the outputs of the amplifier.

Here is a chart that shows the target voltages for some common power levels. This brings up another assumption; that the amplifiers rated power is actually what is claimed (assumption #5 for those keeping track).

Normal Voltage Guide (Use Full Scale Sine Waves)					
Power (Watts)	4Ω	3Ω	2Ω	1.5Ω	1Ω
25	10.0	8.7	7.1	6.2	5.0
50	14.2	12.3	10.0	8.7	7.1
75	17.4	15.0	12.3	10.7	8.7
100	20.0	17.4	14.2	12.3	10.0
125	22.4	19.4	15.9	13.7	11.2
150	24.5	21.3	17.4	15.0	12.3
175	26.5	23.0	18.8	16.3	13.3
200	28.3	24.5	20.0	17.4	14.2
250	31.7	27.4	22.4	19.4	15.9
300	34.7	30.0	24.5	21.3	17.4
350	37.5	32.5	26.5	23.0	18.8
400	40.0	34.7	28.3	24.5	20.0
450	42.5	36.8	30.0	26.0	21.3
500	44.8	38.8	31.7	27.4	22.4
600	49.0	42.5	34.7	30.0	24.5
700	53.0	45.9	37.5	32.5	26.5
800	56.6	49.0	40.0	34.7	28.3
900	60.0	52.0	42.5	36.8	30.0
1,000	63.3	54.8	44.8	38.8	31.7
1,100	66.4	57.5	47.0	40.7	33.2
1,200	69.3	60.0	49.0	42.5	34.7
1,300	72.2	62.5	51.0	44.2	36.1
1,400	74.9	64.9	53.0	45.9	37.5
1,500	77.5	67.1	54.8	47.5	38.8
2,000	89.5	77.5	63.3	54.8	44.8

Target Voltage Chart

One great thing about this method is that you don't need to even know what the voltage is at the inputs. Ever. It would only become important if we need to troubleshoot an issue with the system, but for level setting, this method does not require that you measure that at all. In fact, this is a great time to talk about what an optical signal can do for you!

Optical Digital Audio signals:

If you are able to use an optical signal (typically using a TOSLINK cable) as opposed to an analog signal (RCA cables) for your input, you don't need to worry about setting the input levels at all! If your processor has an optical output, you don't have to worry about any of this level setting stuff at all until you get to the amplifier.

The S/PDIF signal that is transmitted on the TOSLINK cables is a standardized digital stream that is considered to be "full scale", meaning that it is the same as a maximum signal before clipping. One thing to consider when using the digital signal; you do not have the ability to overdrive the input as you might on the analog inputs. This may result in a misleading and inaccurate assumption that the system has "less output". What it actually has is less clipping / less distortion and less noise.

FiX® Target Voltage Guide (Use Calibration Track)					
Power (Watts)	**4Ω**	**3Ω**	**2Ω**	**1.5Ω**	**1Ω**
25	2.5	2.2	1.8	1.6	1.3
50	3.6	3.1	2.5	2.2	1.8
75	4.4	3.8	3.1	2.7	2.2
100	5.0	4.4	3.6	3.1	2.5
125	5.6	4.9	4.0	3.4	2.8
150	6.1	5.3	4.4	3.8	3.1
175	6.6	5.8	4.7	4.1	3.3
200	7.1	6.1	5.0	4.4	3.6
250	7.9	6.9	5.6	4.9	4.0
300	8.7	7.5	6.1	5.3	4.4
350	9.4	8.1	6.6	5.8	4.7
400	10.0	8.7	7.1	6.1	5.0
450	10.6	9.2	7.5	6.5	5.3
500	11.2	9.7	7.9	6.9	5.6
600	12.3	10.6	8.7	7.5	6.1
700	13.3	11.5	9.4	8.1	6.6
800	14.2	12.3	10.0	8.7	7.1
900	15.0	13.0	10.6	9.2	7.5
1000	15.8	13.7	11.2	9.7	7.9
1100	16.6	14.4	11.8	10.2	8.3
1200	17.3	15.0	12.3	10.6	8.7
1300	18.1	15.6	12.8	11.1	9.0
1400	18.7	16.2	13.3	11.5	9.4
1500	19.4	16.8	13.7	11.9	9.7
2000	22.4	19.4	15.8	13.7	11.2

FOR JL AUDIO DEALERS

1) FiX® OEM Integration Processors

During the calibration process, the FiX® processor automatically sets input levels and output levels for you. This is done using the calibration track, and uses logic designed to allow for the user to adjust tone controls (bass, treble, etc.), without worrying about overdriving the inputs (or the outputs). As a result, you can use the chart on this page **ONLY** when using a FiX® processor.

2) VXi / MVi Amplifiers

These amplifiers not only have indicators for setting input sensitivity, but also feature indicators for setting output levels. This makes the level setting method even simpler, although it is based upon the exact same process.

Setting Input Sensitivity on a VXi / MVi:

1) Play an unattenuated sine wave at 75% of maximum volume on the source unit.
2) Launch TüN® software and configure your input connections in the “Setup” tab. Then click the “▮” symbol in the “Inputs” panel. This opens the input sensitivity adjustment controls.
3) Adjust each “Input Level” upward (slowly) until you see the indicator turn red, then go back one number lower than that. Input sensitivity is done.

- When using the analog outputs from a FiX® processor to feed a VXi / MVi input, it is even easier: just set the input sensitivity at “7”.

- If you are using a digital input to the VXi, there is no input sensitivity adjustment. Digital level is known, and therefore preset.

After you adjust input sensitivity, you will go through the normal tuning process. This will no doubt include adjusting Output Level Trim controls relative to one another, so that the system is balanced (tweeters are not too loud compared to the mids, left/right levels are adjusted, etc.). Once you are finished tuning, you can then maximize the output levels.

Maximizing VXi / MVi Output Levels:

1) Adjust your source volume level to 75% and play some demanding music.
2) Click the linking box at the top of the “Outputs” panel to link all Output Level Trim controls together.
3) Using the up arrows, either in the interface or on your keyboard, increase all of the Output Level Trim controls together until any one of the output level indicators either turn red, or you reach maximum level (whichever comes first).

In Conclusion:

We have covered a lot of ground in this training and hope that you find the information useful.

What you have learned in this training should help you make better choices that result in great sounding, reliable systems for your customers and yourself. If there is any one thing that should be at the forefront of your thinking it is that the process of matching amplifier systems to speaker systems and then setting them properly requires some careful thought.

In addition to learning basic concepts of acoustics and electricity, we have covered a lot of highly practical points that should be useful on a daily basis:

- That the amplifier power must be carefully considered against the charging system of the vehicle or vessel and what can be done to upgrade a charging system.
- That the power distribution between subwoofer and satellite speaker systems is critical to achieving great sound.
- That the amplifier power that the speakers actually "see" depends on the music and the listener's habits.
- That setting amplifier input sensitivities properly is essential for good sound and reliability.
- That selling a customer more power than recommended will only create problems and unhappy customers.

But, most importantly, you have learned why these things are true. This will allow you to effectively communicate your recommendations to your customers and co-workers.

It is important to realize that the content of this training just scratches the surface of each topic. There is far more detailed information available that will now be easier to digest because you have learned the basic concepts. We encourage you to seek out more in-depth information on these topics and would be happy to point you in the right direction... just give us a call or drop us an e-mail.

Thank you for participating in "A Short Course in Audio"

Glossary

AC (Alternating Current): Energy that alternates back and forth at a certain frequency. The frequency is measured in Hertz (Hz).

Acoustical Energy: Energy consisting of fluctuating waves of pressure called sound waves.

Acoustic-Suspension Enclosure: An enclosure type where the box is completely sealed. The air trapped inside is compressed and rarefied by the speakers motion and assists the speakers' suspension. See also Air-Suspension Enclosure and Sealed Enclosure.

Air-Suspension Enclosure: A sealed enclosure where the volume of air inside of the box helps assist the speakers' suspensions (as well as the motor) restore the speaker to its center position. See also Acoustic-Suspension Enclosure and Sealed Enclosure.

Amperes (I): Measurement in units for Current. One ampere of current flowing is 6,240,000,000,000,000,000 free electrons passing one particular point each second. Also known as "amps".

Amplification: An increase in signal level, amplitude, or magnitude.

Amplitude: The measure of how much signal is contained in an alternating signal. Amplitude is typically expressed in units of Volts or decibels (dB).

Analog: An electrical signal in which the frequency and level vary continuously in direct relationship to the original acoustical sound waves. Analog may also refer to a control or circuit which continuously changes the level of a signal in a direct relationship to the control setting.

Aperiodic: Describes waves that do not repeat at a fixed time interval and do not produce a fundamental tone. Random noise is an example of an aperiodic signal.

Attenuate: To lessen the amount of force, magnitude or value of something.

Audio Signal: An electrical representation of a sound wave in the form of alternating current (A/C) or voltage.

Bandpass Enclosure: An enclosure type where all of the output comes from a port or ports. See also Dual-Reflex Bandpass, Series-Tuned Bandpass, and Single-Reflex Bandpass.

Bandpass Filter: A device which incorporates both high-pass and low-pass filters in order to limit and attenuate both ends of the frequency range.

Bandwidth: Refers to the "space" in the frequency response of a device through which audio and/or data signals can pass.

Bass: The low audio frequency range, normally considered to be below 125 Hz.

Bass-Reflex Enclosure: A term used to describe an enclosure that has a port or vent that assists the output of the speaker. See also Ported Enclosure.

Bridging: Bridging combines left and right channels of an amplifier into a single, more powerful L & R mono channel. Bridging is common when using an amplifier for a subwoofer application.

Capacitor: A passive two-terminal electrical component used to store electrical energy temporarily in an electric field. Capacitors are widely used in electronic circuits for blocking direct current (DC) while allowing alternating current (AC) to pass.

Circuit: A closed circular path through which current flows from a power source, though various components, and back to the power source.

Circuit Breaker: An electromechanical device designed to quickly break the electrical connection should a short circuit or overload occur. A circuit breaker is similar to a fuse, except it will reset itself or can be manually reset, and will again conduct electricity.

Clipping: A form of waveform distortion that occurs when an amplifier is overdriven and attempts to deliver an output voltage or current beyond its maximum capability.

Compliance: The reciprocal of stiffness. The greater the compliance, the less the stiffness.

Crest Factor: A measure of a waveform, such as alternating current or sound, showing the ratio of peak values to the effective value. Crest factor is the peak amplitude of the waveform divided by the RMS value of the waveform.

Crossover: Splits the audio signal into separate frequency bands that can be separately routed to loudspeakers optimized for those bands. Crossovers are often in a Passive or Active configuration.

Current (I): The movement or "flow" of free electrons through a conductor and measure in units called amperes or "amps"

DC (Direct Current): A flow of electrons that travels only in one direction.

Decibel (dB): A logarithmic unit used to express the ratio of two values of a physical quantity, often power or intensity.

Distortion: Sound that is modified or changed in some way. In a speaker, distortion is produced by several factors, many of which are related to poor construction. Voice coil rubbing (cause by being overdriven) is the most common cause of distortion.

Dual-Reflex Bandpass: A type of Bandpass Enclosure that has ported front and rear chambers.

Dynamic Range: The range difference between the quietest and the loudest passages of the musical selection or program signal being played.

Efficiency: The measurement of a loudspeaker or amplifier's ability to convert input power to output power (work). Formula: Efficiency = (power out/power in) x 100. Efficiency is always expressed as a percentage.

Electromagnet: A large coil of wire that becomes a magnet when current flows through it.

Electromagnetism: The use of electricity to create a controlled magnetic field with north and south determined by the current flow.

Flat Response: An output signal in which the fundamental frequencies and harmonics are in the same proportion as those of the input signal being amplified. A flat frequency response would exhibit relatively equal response to all fixed-point frequencies within a given spectrum.

Fast Fourier Transform (FFT): Displays voltage or energy that is present over each frequency resulting in a more detailed look at a signal than a typical RTA provides (see RTA).

Frequency: The term in physics that refers to a number of vibrations or cycles that occur within a given time.

Frequency Response: A term that describes the relationship between a component's input and output with regard to signal frequency and amplitude.

Gauge: The size (thickness) of wire. Commonly seen for power wire and speaker/signal wire in car audio.

Graphic Equalizer: Equalizer with predefined frequencies that the user can make changes in amplitude at (boost or cut).

Ground: The term given to anything that has an electrical potential of zero. Most modern vehicles are designed around a negative ground system, with the metal frame being the vehicle's ground (electrically also called the "chassis" or "chassis ground").

Harmonic: The overtones and undertones that define the acoustic difference between two sounds with the same fundamental frequency.

Headroom: The difference between the highest level present in an audio signal and the maximum level an audio device can handle without noticeable distortion. A greater amount of headroom reduces the chances for unwanted distortion in an audio system.

Hertz (Hz): The unit for frequency in cycles per second.

High Frequency: Refers to radio frequencies in the 3-30 MHz band. In audio it usually refers to frequencies in the 5-20 kHz band.

High Pass Filter: A network of components which attenuate all frequencies below a predetermined frequency determined by the designer. Frequencies above the cut-off are passed without any effect.

Imaging: The width and definition of a sound stage. Instruments should appear to be coming from their correct positions, relative to recording.

Impedance (Audio): A measurement of the resistance to the audio current by the voice coil of the speaker. Also see, Nominal Impedance.

Impedance (Electrical): The dynamic resistive opposition offered by a device or circuit to the flow of alternating current (AC).

Inductor: An electrical component in which impedance increases as the frequency of the AC increases; also known as "coils" that are used in passive crossovers.

Infinite Baffle: An enclosure that is large enough that the air behind a speaker does not affect its performance. Theoretically the enclosure would have to be infinitely large, but in practice, a volume three time the Vas of the speaker works well.

Infrasonic: Refers to sounds or signals whose frequencies are below the normal human hearing range, generally considered to be 20 Hz.

Isobaric / Isobarik: "Constant pressure". A mounting technique where two woofers are used together as a single unit. The result is a enclosure recommendation that is half what a single speaker would need.

Joule: A unit of electrical energy equal to the work done when a current of one ampere passes through a resistance of one ohm for one second.

Line Output Converter (LOC): Device used to convert a high (speaker) level signal to a low (line) level signal by decreasing the voltage. Often needed for integrating an aftermarket amplifier to a factory head unit with RCA cables.

Load: Any electrical component that is connected to a circuit that consumes electricity.

Loudness: The subjective perception of sound pressure (SPL).

Low Frequency: Refers to radio frequencies within the 30-300 kHz band. In audio it usually refers to frequencies in the 40- 160 Hz band.

Low Pass Filter: A network of components which attenuate all frequencies above a predetermined frequency selected by the designer. Frequencies below cut-off are passed without any effect.

Magnet: A device that can attract or repel pieces of iron or other magnetic material. Speaker magnets provide a stationary magnetic field so that when the coil produces magnetic energy, it's either repealed or attracted by the stationary magnet.

Mechanical Power Handling: The amount of power a speaker can handle before reaching it's mechanical limitations while moving.

Midrange Driver: A loudspeaker specifically designed to reproduce the frequencies in the middle of the audible bandwidth. Most musical energy lies in the midrange band.

Noise Floor: The noise power generated by an audio device in the absence of any input signal. It is generally measured in decibels.

Nominal Impedance: The minimum impedance a loudspeaker presents to an amplifier, directly related to the power applied to the speaker. Actual impedance varies with the frequency applied.

Oscilloscope: A type of electronic test instrument that allows observation of constantly varying signal voltages, usually as a two-dimensional plot of one or more signals as a function of time.

Octave: A halving or doubling of frequency. For example, 40 Hertz is one octave higher than 20 Hertz. 5,000 Hertz is one octave lower than 10,000 Hertz.

Ohm: The unit of measurement for electrical resistance.

Ohm's Law: The statement of the relationship between current, voltage and resistance. Where I = Current, E = Voltage and R= Resistance. $I=E / R$, $E=I \times R$ and $R=E / I$

Parallel Circuit: A circuit with multiple paths for current to travel through. Parallel circuits have the same potential difference (voltage) across their ends.

Parametric Equalizer: An equalizer that allows the user to choose the frequency to make changes in amplitude (boost or cut), as well as the bandwidth ("Q") of the change in amplitude.

Passband: The range of frequencies uniformly passed by a filter. Defined by two frequencies.

Passive Crossover: An electrical circuit consisting of capacitors, inductors and resistors designed to separate an audio signal into specific speaker groups.

Peak: An emphasis over a frequency range not greater than one octave.

Peak Amplitude: Also can be called Peak Voltage, is the highest point of a measured wave.

Peak-to-Peak Voltage: The difference in amplitude between the highest peak voltage and the highest negative voltage. It is equal to twice the peak voltage.

Period: The amount of time required for a single cycle of a sound wave.

Periodic: Describes waves that repeat the same waveform over and over again and produce a fundamental tone. Sine waves and square waves are periodic signals.

Phase: A measure of time in degrees where 360 degrees is equal to one cycle. Phase is related to frequency.

Phase Shift: Frequency interaction in the crossover region of passive crossovers that can cause some frequencies to be delayed with respect to other frequencies.

Pink Noise: Random noise with equal energy per octave covering 20Hz-20kHz that is often used as a test signal.

Polarity: In electricity, refers to the condition of being either positive or negative.

Ported Enclosure: An enclosure type that uses a port to couple the energy from the rear of a speaker with the energy from the front. See also Bass-Reflex Enclosure.

Potential: The electrical charge that allows work to be done in a circuit. Potential is commonly called Voltage. A circuit must have an electrical potential for electrons to flow.

Potentiometer: A variable resistor made with either carbon or wire wound material that attenuates (adds resistance) to a signal. Often used to set the input sensitivity of an amplifier.

Power (P): The amount of energy (in joules) that a device delivers or consumes divided by the time (in seconds) that the device is operating.

Pre-amp: A circuit unit that takes a small signal and amplifies it sufficiently to be fed into the power amplifier for further amplification. A pre-amp includes all of the controls for regulating tone, volume and channel balance.

Qtc: Measurement of a speaker and enclosure working together as one. When applied to enclosure design, in particular sealed boxes, it is a gauge to the frequency response shape.

Qts: Measurement of the speaker as a motor, taking into consideration all mechanical and electrical losses.

Range: Usually described as frequency range, this is a system's frequency response, beyond which the frequency is attenuated below a specific tolerance. Also, the frequency bands or bands with which a receiver or component is designed to operate.

Resistance (R): The opposition to current flow. Greater amounts of resistance result in smaller amounts of current flow when a given amount of voltage is applied.

Resistor: A passive two-terminal electrical component that implements electrical resistance as a circuit element. Resistors act to reduce current flow, and, at the same time, act to lower voltage levels within circuits. In electronic circuits, resistors are used to limit current flow, to adjust signal levels, bias active elements, and terminate transmission lines among other uses.

Resonant Characteristic: The frequency at which something resonates at. All things have resonance, and in the case of a Ported Enclosure, this resonance is used to assist the speakers output.

Roll-Off: Relates to the attenuation of frequencies, above or below a given point at a specific state.

RTA (Real Time Analyzer): A professional audio device that measures and displays the frequency spectrum of an audio signal. Often used to view an audio system's equalization for tuning.

Sealed Enclosure: An enclosure type that uses the air trapped inside of a completely sealed enclosure to affect the motion and therefore the performance of the speaker. See also Air-Suspension Enclosure and Acoustic-Suspension Enclosure.

Sensitivity: The rating of a loudspeaker that indicates the level of sound intensity the speaker produces (in dB) at a distance of one meter when it receives one watt of input power.

Series Circuit: A circuit where resistances are connected in a straight line (like a chain) and allow only one current path. The current in a series circuit goes through every component in the circuit. Therefore, all of the components in a series connection carry the same current.

Series-Parallel Circuit: A circuit where resistance occurs when both series and parallel resistances are present.

Series-Tuned Bandpass: A type of Bandpass Enclosure that has a rear section with a speaker and a port that fire into a second ported chamber. The output from the enclosure comes from the second ported chamber.

Short Circuit: The condition that occurs when a circuit path is created between the positive and negative poles of a battery, power supply, or circuit. A short circuit will bypass any resistance in a circuit and cause it to not operate.

Signal-to-Noise Ratio: The S/N ratio indicates how much audio signal there is in relation to noise, or a specified noise floor.

Sine Wave: Short for sinusoidal wave, is a mathematical curve that describes a smooth repetitive oscillation.

Single-Reflex Bandpass: A type of Bandpass Enclosure that has a sealed section and a ported section. All of the energy from the system comes through the port or ports in the ported section.

Sound: A type of physical kinetic energy called acoustical energy.

Sound Waves: Fluctuating waves of pressure that travel through a physical medium such as air. An acoustic wave consists of a traveling vibration of alternate compressions and rarefactions, whereby sound is transmitted through the air or other media.

S/PDIF (Sony / Philips Digital Interface): A type of digital audio interconnect that can be transmitted over either coaxial cables or TOSLINK cables (see below). Usually used with two channels of uncompressed audio but can also be used to transmit compressed 5.1 or 7.1 (surround sound).

SPL: Sound pressure or acoustic pressure is the local pressure deviation from the ambient (average, or equilibrium) atmospheric pressure, caused by a sound wave. In air, sound pressure can be measured using a microphone. Changes in SPL are measures in decibels.

Square Wave: A non-sinusoidal periodic waveform in which the amplitude alternates at a steady frequency between fixed minimum and maximum values, with the same duration at minimum and maximum.

Staging: The accuracy with which an audio system converts audible information about the size, shape and acoustical characteristics of the original recording space and the placement of the artists within it.

Stopband: The range, or ranges of frequencies outside the passband (See Passband above).

Subwoofer: A loudspeaker made specifically to reproduce frequencies below 125 Hz.

Symmetric Tuning: A term used to describe the recommended tuning frequency of a Ported Enclosure or Bandpass Enclosure. This frequency will usually ensure a smooth, even response.

Thermal Power Handling: How much heat a loudspeaker can dissipate without significantly compromising performance and/or failing completely.

TOSLINK: A proprietary connector style developed by Toshiba used in optical connections on digital audio products.

Transducer: Any device that converts energy from one form to another, e.g., electrical to acoustical or vice versa. Loud speakers and microphones are two types of transducers.

Transfer Function: The change in the low end of a low frequency system brought on by loading the device into the cabin of a vehicle.

Transient Response: The ability of a speaker to follow the signal that it is sent.

Tuning Frequency: The frequency at which a port resonates.

Tweeter: A small loudspeaker or driver meant to reproduce high frequencies.

Uni-Body Chassis: A vehicle chassis design where the frame and main body cavity are integrated into a single structure. For more see, Ground.

Vas: Mechanical compliance. A measurement in liters or cubic feet of the volume of air that is equal to the compliance of a speakers total suspension.

Vented Enclosures: A type of enclosure that uses a vent (port) to couple the energy from the rear of a speaker with the energy from the front. See also Bass-Reflex Enclosure.

Voice Coil: A coil of wire that takes in the electrical energy coming from the amplifier and converts it into acoustical energy or mechanical motion.

Volt: The term used to refer to the property of electrical pressure through a circuit.

Voltage (E): The difference in electric potential energy between two points per unit electric charge.

Voltage Drop: The amount of energy consumed when a device has resistance in its circuit. The voltage (E) measured across a resistance (R) carrying a current (I). E= I x R. See also, Volt.

Watt: The basic practical unit of measure for electrical or acoustical power.

Wattage: Electrical power.

Watt's Law: Similar to Ohm's Law, it demonstrates the relationships between Voltage (E) and Current (I) to represent a quantity of Power (P). With the Watt's Law formula, knowing two elements can mathematically compute the third element. $P=E \times I$, $P=I^2 \times R$ and $P=E^2 / R$

Wave: A single oscillation in matter (e.g. a sound wave). Waves move outward from a point of disturbance, propagate through a medium and grow weaker as they travel farther. Wave motion is associated with mechanical vibration, sound, heat, light, etc.

Waveform: The shape of a wave, typically viewed on an oscilloscope.

Wavelength: The length of distance a single cycle or sound wave travels.

Woofer: A large dynamic loudspeaker that is well suited for reproducing bass frequencies, typically 6-18 inches in diameter when used in car audio applications.

Xmax: The distance that a speaker can move while keeping a constant number of voice coil windings inside of the magnetic gap of the speaker. It is listed in either inches or millimeters in one direction.

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