Getting Grounded

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Aaaaaaaaaaaarrrrrrgggggghhhhhh!!!! Why is it that after more than 20 years in this industry we **still** have to train on this?!

Why is it that one of the simplest issues remains confusing to so many of us?!

Why can't we get past basic things and on to cooler, more fun things, like watching paint dry?!

What could possibly be so basic and so misunderstood to elicit such a strong position? You might think it is "how do I find the right speaker wires to tap into?" or "what is the best subwoofer for my car?". No, sadly, those topics are far more complicated than the one that has me all upset (again).

"There ought to be a law"

Let me start by saying that your 2000-watt amplifier is not 2000 watts. I don't care what the 'birth certificate' says. I don't care what the test reports say. It does **not** deliver 2000 watts in your vehicle. Certainly not with the music you're listening to. And the reason is part of the reason I get so upset over this topic. Two words: Ohm's Law. It is one of the rare moments in life, let alone mobile audio, that we have a **law** that helps us determine what is **real**. Let me explain.

In order to deliver a true, continuous 2000 watts of power in your standard automobile, you would need more than that much power from the vehicle electrical system. I know this is true because of Ohm's Law. With Ohm's Law, we know that Power (in Watts) is equal to Voltage (E) times Current (I). Your car has a 12-volt charging system (E = 12) and even a heavy-duty alternator in your vehicle is going to have about 140 amps of current available (I = 140). So, using P = I * E, we find that P = 140 * 12 or P = 1680 Watts. **Not** 2000 watts. And remember, this is the available power in Watts from the **entire** electrical system, not just what is available for your amplifier.

But I know what you might be thinking; "But when my vehicle is running, it is not 12 volts…it is higher". Fine. Let's run numbers again. Start the engine. Measure the battery. What do you get? (We will discuss how you measure this in a bit). 13 volts? Maybe 14? Let's use the famous 14.4 reading (E = 14.4). So now we have P = 140 * 14.4 which works out to be 2016 Watts. "Ah HA!" you scream! "2000 Watts, baby! In your FACE!" Not so fast. This is, remember, total available power for the entire electrical system, not just the power for your amp. But even if that was the case, there is a very important factor left out of this equation that needs to be considered; Efficiency. This magical amp of yours would have to be 100% efficient. It's not. Nothing is. But even if it were, your 2000 watts would not hold up long enough to be meaningful to you. After the first impulse of music, your electrical system is going to be pushed (or is it pulled?) to its limit; and will need to dip into that ever popular reserve tank also known as your battery. That is where things can get ugly and fast. The battery can only provide so much power for so long. Once you dip into the power from the battery, it becomes a load on the alternator, which reduces the amount of power available for your magical 2000-watt amplifier. You may be able to cheat for brief moments in time, but eventually you **will** pay the price. That price may be a failed battery, a failed alternator or a failed amplifier. Not necessarily in that order or in isolation. How quickly this will happen can and will vary on too many factors to list here, but it is not a matter of **if**; it is a matter of **when** because it **will** happen. Unless…

You might be thinking that I am insane. You are probably right, but when it comes to this topic, I may not be. You might be wondering how is it that you've had this magical amp in your car without any failures as listed above for years. The simple answer is right where we started; your 2000 amplifier is not 2000 watts. We were doing all of our math based upon the presumption of "what would I need to make 2000 watts of power". Let's look at it differently. Let's look at it from the point of view of **most** amplifier designs. Most amplifiers utilize what is known as an unregulated power supply. Simply put, this means that the supply voltage determines how much power the amplifier might be able to produce (assuming you have the current capacity). In other words, if you have higher supply voltage, you have higher potential output power from the amplifier. In reality, you do **not** have higher supply voltage; so logically that means you have **lower** potential output power. Now if you think about that for a moment, it should occur to you that maybe, just maybe when the supply voltage is lower, the true potential of the amplifier will be lower too, and you would be right. Since we are dealing with a battery that is rated at 12.6 volts, if you were to use that for your calculations, you would see about a 30% drop in power potential (actually it is almost 40% in this case, but whose counting?). This is really not a big deal since 1200 watts is still a **lot** of power (we can discuss the '3dB rule' another time).

You can keep looking at the numbers if you like, but the true point is that your amplifier is not doing what you think it is doing, especially when it is unregulated (as most amplifiers are). The point that drives me nuts typically shows up when working with **regulated** amplifiers. These designs will do whatever possible to deliver their rated power even if supply voltage sags (which it does). Knowing Ohm's Law, if power is fixed and the supply voltage sags, the power has to come from somewhere. Any guesses? If you said, "the current must go up", you've been paying attention. Let's look at this a bit differently.

As Ohm's Law states, P = I * E right? So, if our regulated amplifier is rated for 1200 watts as an example, and our voltage is 12 volts (it makes the math easy), we would need 100 amps of current; 1200 = 100 * 12. If, however, the voltage drops to 10 volts, in order to **keep** the 1200 watts, the current would **have** to increase to 120 amps. No free lunches here. A regulated amplifier will do whatever it takes to get you the full rated power. At some point, your electrical system may not like that, and then you may run into trouble. What kind of trouble? Well, oddly enough, that is the point of this paper.

When you have a device that is designed to work hard towards achieving a certain goal, all factors must be considered. In the case of regulated amplifiers, some of those factors need to include the realistic available power in a typical vehicle. If you anticipate that the charging system is always going to deliver 14.4 volts and 140 amps of current, you are going to be pretty disappointed with the results. Knowing this, most companies will build in some form of protection so that the amplifier does not either do damage to the charging system or itself. The most common protection is abrupt, but effective; it shuts off if the supply voltage sags too low. This low voltage threshold is intended to keep the battery and alternator system happy, or perhaps a better phrase is 'not as upset'. Similarly, since the output devices on the amplifier use the supply voltage to function, one impact low supply voltage can have on these devices is a huge increase in heat. That heat can and will damage the devices. So in addition to trying to keep your charging system happy while still giving you every watt you have paid for, the shutdown behavior is also intended to prolong the life of the output devices (and keep the amp in your vehicle longer).

If you have not stopped reading this yet, you must be wondering if I am really getting all worked up about regulated versus non-regulated amplifiers. I'm not. But in order to explain the topic that does work me up, it is necessary to explain the differences because it is clear from the number of calls and emails my team receives on a daily basis (not to mention the countless calls and emails that we **don't** receive…) that too many people don't understand how these different amplifiers designs behave. With that out of the way, I would like to introduce you to what seems to be the least understood topic in mobile audio history and remains the king to this day:

Grounding and power management

I am guessing that many of you just groaned a bit. Good. But please keep reading. If you groaned because you know this stuff already then you're hired as an ambassador to teach everyone else. I need you to proofread. If you groaned because you are tired of manufacturers blaming the installer for issues, then let me introduce you to the others that groaned and were just hired as ambassadors. Either way, I would expect everyone to keep reading.

Some clarifications

Before I go any further, let me clarify some terms and phrases: "Clipping" is 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 (http://en.wikipedia.org/wiki/Clipping_(audio)). It is not a valid or accurate description of an amplifier that is turning off. "Going into Thermal" means that the amplifier is getting hot enough to engage the thermal protection circuit. How the amplifier behaves when this event occurs will vary between various brands and models, but in almost all cases, there is some type of indication (a light or something like that) that will let you know a thermal event has occurred. It is not a valid or accurate description in most cases to describe an amplifier that is shutting off (as opposed to going into protection). "Shutting off" is a term that is used to describe when an amplifier actually shuts off. This means the lights go **off** or in some cases there are indicators that tell you that the amplifier has gone into a special shut down mode due to low voltage. Notice how only **one** of these three terms refers to an amplifier that actually turns off. This is important, of course, especially when trying to troubleshoot why you may not be getting any audio from your amplifier.

So the question is, what would cause an amplifier to go into protection or shut off from low (supply) voltage? The answer is incredibly simple. You don't have enough supply power. Period. If the amp is shutting off due to low voltage, a case that is almost exclusive to high power, regulated amplifiers, the reason is so obvious it often escapes detection. Ohm's Law proves it and that is the reason I spent so much time explaining how it works and how regulated amplifiers work. There is no mystery here. The math is simple and repeatable. So why does this cause so much confusion?

I have a hypothesis. In general, we are an industry of lazy (or perhaps uninformed) people. Our troubleshooting skills appear to be primitive at best. For example, when an amp shuts off, the most likely course of action is to replace it with another amp (same model). If that amp shuts off too, we put in a different amplifier. If that one stays on, then the other two amps must be bad; either defective or 'crap'. This is not troubleshooting. This may prove two things though: 1) the installer is lazy and 2) Ohm's Law works. It does not prove that the amps are bad or 'crap'.

There are only a few companies that offer regulated amplifiers. Having worked for one of the few for 20+ years, I can tell you that I completely love the idea of a regulated amplifier and I also understand why so few companies offer them. Regulated amplifiers can offer incredible sound quality by maintaining consistent power delivery. They do this at a cost, of course. One is monetary. Since the design itself is more complicated and involves more parts, the end product tends to cost a bit more. The other cost is the impact it can have on the installation. As a result, I understand why most companies do **not** offer regulated amplifiers. The calls and emails, particularly with higher power designs, can be overwhelming. It is a lot easier to offer unregulated amplifiers and call it a day than to walk the path less traveled.

So back to my hypothesis. Since so few companies offer regulated amplifiers, most of the time when the shut down issue rears its head, the replacement amplifier will most likely be non-regulated. And as we have learned, the non-regulated amplifier will simply produce less power rather than cause a significant voltage drop (well, it could happen, but it would take a **lot** more time / power / power over time). When a very lazy (uninformed?) installer simply pulls a regulated amp out since it was shutting off and puts in a non-regulated amplifier with similar rated power, they have not fixed anything.

A more ambitious installer might try to determine why the amplifier shut down in the first place. They grab their multimeter and measure the voltage. Seems logical enough. Unfortunately, this method is not going to show anything useful (unless things are **really** messed up - and even then it is only minimally effective). When I tell you that every meter you are likely to use or have access to is going to give you inaccurate readings when you measure the voltage at the terminals of the amplifier, I am not exaggerating. Even if you were to play sine waves and measure the voltage, it is unlikely to show you the true value that you are looking for. The amplifier shutting down will do a better job of indicating the voltage drop than your meter will. There are many reasons for this, but rather than try to explain them all, I would much rather focus on the **right** way of checking things.

When we are dealing with amplifiers, especially amplifiers that are powerful enough to even have to talk about sagging voltage, we are not talking about a 'normal' electrical device for a vehicle. Consider that a headlight is typically going to be about 50 - 60 watts. Let's see what Ohm's Law can tell us about the current draw for a pair of 55 watt headlights. If we use a voltage of 12 ($E = 12$) and our total power in watts is 110 ($P = 110$), then we can solve for current and find that $I = 9.17$. Call it 10 amps. Hmmm. That makes me wonder. If 110 watts of headlights draws around 10 amps...an amplifier that was 1100 watts would then draw around 100 amps of current. Interesting, no? Which is the point, actually. Headlights can be among the most demanding current hogs in a vehicle (the starter motor is pretty bad too). There are other hogs in the vehicle, of course, but I use headlights because very often customers will complain when they dim; which is a clear sign of a power delivery issue. So if we wanted to measure what is going on electrically with a headlight, what would we normally measure? With Ohm's Law, we need two variables to get pretty much anything else we might be looking for. The bulb may be rated at 55 watts, but that does not mean it is **always** 55 watts. In fact, since they dim, you can actually **see** that the power fluctuates. If you turn off everything in the car (audio system, climate control, etc.) you can measure the voltage and perhaps, if you have the right meter, the current draw and calculate the power from those. You will probably measure around 13.6 volts (with the engine running) and around 4 amps of current; giving you around 55 watts per bulb (you would have to measure each bulb independently). If you were to click on the climate control and monitor your meters, you would probably see a brief drop in the voltage (visually represented by a brief dimming of the headlights) and a flicker of a change in current. Headlights are easy compared to amplifiers. The impact that turning the climate control on had on your readings is happening frequently and often times at levels much more significant (a powerful amplifier is a harder load than the climate control). The duration of the event(s) may be very short which is one key reason your meter does not read it properly. Directly measuring these short duration, massive drains on a power delivery system is almost impossible. You can, however, measure **other** variables to determine what might be happening.

The three main variables of Ohm's Law that we have a shot at measuring are current, voltage and resistance. Of these, current is arguably the most challenging. There are, basically, two ways to measure current. One is to use a meter wired into the circuit and pass current through the meter for it to measure. The meter I have here has a fuse value of 10 amps, so measuring anything above that will obviously be an issue. I think it is safe to say that measuring draw of 40 amps and higher is not going to happen with the in-line approach. The other method involves a clamp around the wire being measured. This is actually pretty neat. It is basically measuring the field around the wire that is created when you pass electricity through it. Very cool. This can get a pretty good reading on a steady draw but any rapid, brief surges would be difficult to read with a high degree of accuracy.

Resistance *is* futile. Well, measuring it is.

We have already discussed some of the issues associated with measuring voltage (the traditional way, anyway). So let's see how to measure resistance. This one seems to be the easiest. Grab your meter, touch one probe on one point and the other on the other point and you get a reading on the screen. Simple enough, no? Well, it is probably a good idea to consider exactly **how** the meter works to give you that reading. Guess how it does it. Yup, Ohm's Law. The meter sends out a small, known current and records the voltage between the probes and calculates the resistance. I was playing with two meters I had here to measure a resistor. One meter was measuring resistance and it read 3.9 but would occasionally jump to 4. I used the other meter to measure the voltage and it read a pretty stable 1.3mV (0.013 volts). In order for the meter measuring resistance to get a reading of 3.9 - 4.0, the current would have to be about 0.0033 amps. Pretty tiny. Just kind of fun to see this all working. The power would calculate out to be 0.0000429 watts. Not quite the same as a monster amplifier.

As my little experiment above shows, the meter works by sending a known current and using the voltage reading to determine the resistance. In our system, however, the current is not going to be 0.0033 amps or anywhere near that. Earlier we were looking at 14.4 volts and 140 amps of current and similar high current situations. Let's see what would happen if we were to scale things up a bit to try and see how accurate the meter is at measuring the true resistance in a high current application. Instead of that tiny 0.0033 amps, let's use 100 amps (no, your meter can not supply that amount, this is just math for now). With the same measured voltage (0.013 volts), your resistance would work out to be 0.00013 ohms. That is **well** outside the range of your meter. Most quality meters will have resolution of 0.1 or maybe 0.01. Lab grade is 0.001. In other words, you cannot accurately measure resistance across a high current part using a meter because the current it provides is not the same as the current that the part may actually see.

So how can our more ambitious installer determine what is happening when the amplifier is shutting down. Calling Technical Support is almost always a futile effort. What do they know? They just say to "check the grounds". The installer just ***loves*** to hear that too. Resorting to calling Tech usually happens after they try measuring the voltage at the terminal of the amplifier (ineffective and inconclusive as we have seen) and probably after using the meter to measure the resistance of the connections and of course 'the ground'. Measuring current is difficult and, honestly, not going to help very much for the same reason that measuring the voltage at the amplifier is not effective.

Would you believe that the issue that made me scream at the start of this article is this issue of "measuring the grounds"? Despite going through all of what we have just been through, the act of measuring grounds is so simple it should never even come up. Everything we just covered proves this. Run numbers. Run tests. Both will bear this out. If the amp stays on at lower levels for hours but shuts down at higher levels after minutes; proof. If a regulated amplifier shuts down and a non-regulated amplifier does not; proof. Want to measure it? We actually can get pretty close. But not by using the normal methods. We need to measure the **drop** in voltage, not the actual voltage.

This is a pretty simple test but it does require that you throw out any hope at an exact answer and learn to accept confirmation of an issue as the end result. Since those darn Tech Departments are always yelling about checking the ground, I will use that for my example. Grab your meter. Set it to measure DC Voltage and after you zero out the leads (you may need **very**long leads, so this is an important step), touch one probe to the -12v connector on the amplifier and the other probe to the negative terminal on the battery. Then play music. Loud. Just like you would when you are enjoying your system. You will see the meter reading jumping around quite a bit as the music plays. Keep playing it and if you are lucky enough to get the amplifier to shut down, try to note the voltage reading when that happens (if your probes are set right, the peak hold or MIN/MAX feature may come in handy). If your amplifier is expected to draw around 100 amps of current, any reading that is higher than about 0.4 volts indicates an issue with, in this case, the ground. You can repeat this test on the positive lead (one probe on the +12 on the amp and the other on the positive side of the battery). You will probably find that the voltage reading on the positive side will be **less**than on the negative side (that is how we know that the ground is the culprit). If you really want to 'drill down' and find the weakest link, you can reduce the gap between the probes. You can measure between the amp terminal and the ground block. You can measure from the battery terminal to the chassis of the vehicle. You can measure between the connection to the chassis at the back of the vehicle and the connection to the chassis at the front of the vehicle. The chassis is usually the culprit, honestly. In various tests that we have done, we have found that in most cases, the chassis is only good for about 100 amps of current. Above that, the voltage drop (which is reflective of the resistance - higher readings indicate higher a resistance) becomes an issue. You can help by running an additional ground wire between the connection in the rear and the connection in the front. I would suggest that any time you run a primary wire larger than a 4 AWG, you should consider adding at least a 4 AWG between those two connection points (Shown in the image below by measurement #5). Try it. You will be able to measure the improvement and most likely realize the benefit by having the amplifier stay on.

I get upset over this issue because there is no reason you should even want to or have to measure anything. You can predict the problem before you even start the installation, hell; you can prevent it at the point of sale / purchase. Know and understand the charging system and how it works. With the way people are listening to current music, you cannot reliably get 2000 watts from any normal charging system. With unregulated amplifiers, you will get less output power usually in the form of increased distortion - but this is not as audible as you might think, so it will go unnoticed in most cases. With regulated amplifiers you will possibly have the shutdown behavior. The point is that with either, there will be problems.

When less is more. More reliable.

With the success of higher efficiency amplifier designs, we are seeing more and more amplifiers rated to deliver huge amounts of power. This seems to have coincided with a tendency to put a lot of power on a single speaker. This has not only resulted in an increase in speaker failures but also to amplifier or, more accurately, electrical system failures. The trend indicates a growing and understandable desire for more powerful subwoofer systems. There are better ways of achieving this than putting in these monster amplifiers, especially if you are not going to address the electrical system. By using more speakers (two 10's instead of one as an example) you can use less electrical power and achieve the same or similar output.

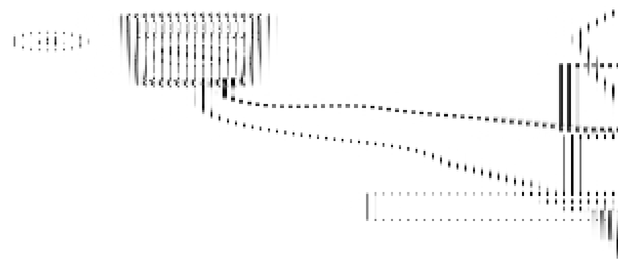

Image courtesy of Todd Ramsey

Even if you don't care about any of that, improving the electrical system, specifically the often-overlooked voltage drops, will improve just about every aspect of the vehicles performance. An article in Car Audio and Electronics magazine a number of years ago entitled "Hyper Ground System: Grounding your way to more horsepower" written by Casey Thorson focused on the improvement in horsepower as a result of improving several OEM ground wires. There is another article (I regret I am not sure where I found this) by Mark Hamilton entitled "Voltage Regulator, Alternator and Battery Operation: How it works…". Back on April 15, 2009 there was an article written by Todd Ramsey on Installer Central under the Installer News section entitled: "Tech Tip: Alternator Basics" that also explains things quite well. Not to be outdone (he rarely is, if ever…), Richard Clark wrote a great paper for CarSound magazine under the column "In The Know" back in September / October of 2001 entitled: "Big Bad Grounds: Debunking the 12-volt myths behind bad grounds". Richard Clark is also a key part of several articles written in the Autosound 2000 Tech Briefs (I have noted seven different articles from A2TB and highly recommend grabbing the collection: http://www.davidnavone.com/as2k/autosound_techbriefs_thebook.htm). One book that I refer to more than any other on this, and many other topics is called "Interstate Automotive Electrical Clinic" put out by, obviously, Interstate Batteries. The copy I have is from 1991, but the original printing was in 1986. I have not had any luck locating a source for this great resource, unfortunately. I have drawn from each of these references and brought some of my own efforts along with those of our team here and many other talented people. As you can see (with references back from 1986), this topic is not new, yet it remains so misunderstood, I thought we could all benefit from a nice, short 4500 word refresher.

Final note: Most of what is written above is intentionally general in nature. I know there are exceptions and more elaborate explanations to phenomena that happen in vehicles, but the nature of this article was to address the vast majority of issues that I encounter.

(PDF copies of most of the referenced documents are available upon request - with credit given to the original authors)