

PERFECTWAVE AC SERIES POWER CABLES



PERFECTWAVE AC12 POWER CABLE

PerfectWave AC Series Power Cables

History

The importance of AC power quality in maximizing a high-end audio system cannot be underestimated. Everything we see and hear in an AV systems starts out as AC power and the quality of that power plays a major role in the system's performance. To address these issues, PS Audio introduced the world's first and most effective AC power solution, the Power Plant AC regenerator in 1997. The Power Plant AC regenerator took any quality AC wall voltage, converted it to DC voltage, and then regenerated perfect, regulated, low distortion AC power capable of powering a high-end audio or video system perfectly.

In 1999 we furthered our mission of delivering pure AC power to high-end audio and video systems when we completed the power delivery chain with the introduction of the Lab Cable. PS Audio's Lab Cable was perhaps the very first high-end power cable of any consequence to hit the marketplace and demonstrated a noticeable improvement to connected equipment. Today there are many high-end power cables on the market that have followed suit, but the experience and knowledge gained from this early start has benefited all future designs of PS Audio power cables.



PerfectWave AC12



PerfectWave AC10



PerfectWave AC5



PerfectWave AC3

Why power cables make a difference

Aside from the obvious answer of making sure power cables do not restrict the AC power delivery, it may not be obvious why a high-end power cable makes any difference when compared to an off-the-shelf cable. Consider the viewpoint that a power cable connecting a piece of audio equipment to the AC power source is but the last few feet in several hundred feet of wire that connects to the power source. Why should it matter?

The main reason is noise immunity as well how transformers in connected equipment interact with the outside world. Understanding these issues requires us to look at a power cable a little differently.

The traditional viewpoint of a power cable is that it is the last link in a long chain of power delivery. In fact, it is actually better to view it as the beginning of the chain instead. Viewed as the beginning rather than the end is certainly a more technically accurate viewpoint as we shall see when we consider shielding as our first example.

Shielding provides noise immunity from outside the power cable as well as from inside the power cable. The noisiest electrical environment in our homes is actually the equipment being powered itself. Computers, high fidelity equipment, video equipment, power supplies of all types generate a surprising amount of electrical noise. The levels generated by the equipment far outweigh any other noises in the home (typically) and so the importance of shielding makes a lot more sense when you view the source of the noise as the beginning of the chain.



In the same way, it is important to also think about this reverse view when it comes to coupling the equipment's power supply with the transformer outside your home that is delivering the power itself. In a well designed high-end power cable the two main conductors are designed in such a way that electrical interactions such as inductance and induced problems such as radiated current spikes (caused by the diodes in the power supply) are minimized. In typical house wiring, the opposite is true. By using a properly designed power cable to help terminate and isolate the power transformer of the equipment being powered, a small improvement can be gained, relative to connecting the equipment directly up to the inductive and unshielded in-wall power cable in your home.

Power cable designs

The fact is, there's not much real scientific research that has been performed on why power cables sound different on different systems. There certainly is a lot of speculation and pseudo science about this subject, but to date no one has really spent the time and effort required to perform rigorous scientific investigations into the causes of cable performance. Despite the lack of measured results, there is no dispute amongst those of us that listen on a high-end system that those difference exist and can have a profound effect on a high resolution system.

What is known are the effects of wire gauge, skin effects, dielectric properties and shielding. The balance of techniques used in cable design are learned skills perfected over years of listening, tinkering and trial and error by dedicated cable designers.

The work of designing a cable performed by the engineering staff at PS Audio is no different. Over the last several decades hundreds of designs have been tested, the results noted and the data logged in. Most testing is performed in the PS Audio reference lab and designs are evaluated for positive and negative sonic attributes on a variety of equipment by qualified listeners.

In this white paper we will speculate as to the reasons we believe our designs produce the results we and our listening panels hear. While these speculative conclusions are based in scientific fact we have not taken the time and effort necessary to prove they are, in fact, accurate. Frankly, the time required to perform such investigations and provide scientifically acceptable conclusions is beyond our team's budget.

What we can suggest with great confidence is that the design methods we employ and the products they produce do, in fact, possess the qualities of performance we describe. This white paper is an attempt to bring to your attention our design methods and conclusions, based on years of research and trial and error design, with a few mentions of our speculation as to why these characteristics in cables designs perform the way we hear them.

A short primer in design

There are 4 main areas of interest in power cable design.

1. Construction geometry
2. Overall conductor gauge
3. Shielding
4. Conductor and dielectric materials

How does a designer decide which of these parameters is most important to their design? Experience.

Designing cables is like cooking food. Take bread baking as an example. Bread is made from 4 simple ingredients:

1. Water
2. Flour
3. Yeast
4. Salt

Yet from these 4 ingredients we get hundreds of types of bread. It is the skill of the bread maker and how he manipulates the 4 variables at his disposal that determines how the bread comes out; and so it is with power cable designs. Using the proper combination of the 4 main variables listed above yields everything from great to unacceptable power cables and everything in between.

Choosing the variables

Sometimes the easiest way to grasp a difficult concept is to view the results of the concept in its extremes. For example, we know from years of experience that if we compare the performance of a 12 gauge stranded power cable vs. the performance of a 12 gauge solid core power cable, the differences are immediately obvious even to the untrained listener. Connected equipment will seem to have less bass and better higher frequency performance with the stranded power cable while the opposite will be true with the solid core cable.

Technically speaking, both should deliver identical performance in the bass areas but in fact they do not. Why?

For years it has been speculated that stranded conductors deliver poor bass response because of their relatively low core diameter, increased surface area (skin effect) and increased flux density as compared to large gauge solid core conductors which have large core areas, decreased skin effect and decreased flux density.

Our trial and error research has shown a different story. In fact, the bass response of stranded vs. solid core is about the same as cable theory would suggest. What's different is the higher frequency improvement provided by stranded conductors (due to the increased skin effect) vs. the reduced higher frequency balance of solid core conductors. In the human hearing system, the brain interprets the loudest frequency range as the dominant default baseline for level. This means any time you have an exaggerated higher frequency range the lower frequencies will seem less.

A great example of this has been a design hallmark of one of the largest consumer audio brands in the world. This well known brand makes extremely small loudspeakers in several of their system and these speakers are incapable of producing much low bass because of their small size. If the engineers of this

brand allowed their speakers to have full range capabilities (up into the upper octaves), then the system would sound bright and tinny. As mentioned above, this would be caused not by a high frequency exaggeration but by a lack of bottom end. In other words, the balance would be off.

Cleverly, the engineers realized that they must sacrifice the high frequencies in the same proportion as the low frequency loss so that the overall presentation of the system sounds natural and not bright. It may seem counter intuitive to increase the perceived bass level by reducing the high frequencies, but this is in fact something that works very well.

To the human ear, balance and flat response mean everything. So it is with power cable design as well.



The conclusion we draw from this in power cables is

one of the most important characteristics we value in a properly design power cable; balance. Nothing should be exaggerated in the design. Knowledge of this type is necessary to understand the design possibilities and manipulate the variables to produce the results we want to listen to.

This knowledge leads us to the current state of the art in power cable design techniques: the art of mastering the perfect balance of frequencies in a power delivery system.

The PerfectWave AC Series geometry

The PerfectWave AC Series of power cables from PS Audio is the finest and best balanced power cable line we have ever built. The line consists of 4 models, the AC3, AC5, AC10 and AC12. The construction geometry of each of these cables is based on the same techniques which we will describe in this section.

The performance goals for the AC Series focused on creating a perfectly balanced power cable. Each of the 4 models would incorporate the same construction geometry blended in such a way that the limitations of each model would not upset the delicate balance we were looking for.

As discussed in the section on choosing variables, balance in a power cable is achieved by first fully understanding the major variables that affect perceived frequency balance in the system and then blending by ear the proper combination of these variables to achieve the desired sound.

Breaking the variables into separate groups was the first step in our design. Our experience has shown us that we can achieve a remarkably balanced and seamless power delivery system by breaking the conductor geometry into three groups:

1. Bass
2. Midrange
3. Treble

In previous generations of AC power cables, the PS Audio designers relied on varying the wire gauges to perfect the performance of each of the three groups. What we discovered during the early days of our work is that using multiple gauges of wire is effective but leaves much to be desired. Bass was never really an issue. The problems came from the midrange and treble regions, with the midrange being the most problematic.

Common sense would dictate that if large gauge (diameter) wires worked well for bass and small gauge wires worked well for higher frequencies, then medium gauge wires would work perfectly for the midrange or middle frequencies. Our work has shown that while this is in fact true, we were never able to get just the right amount of surface area and core size to achieve what we wanted in the midrange. What we needed was more surface area than core size, but to achieve that the classic ratio found in a round diameter conductor would have to be manipulated. Unfortunately, this is impossible in a round conductor.

In a round conductor, the core size and surface area scale proportionally in a fixed ratio as the diameter changes. It was obvious to our designers that if we wanted an asymmetrical ratio of surface area and core size to play with, we would have to look elsewhere for our solution. We first tried bundling smaller gauge and medium gauge wires together to increase surface area. This worked, but not very well.

We then found a solution in patent 6,969,805 of the US patent office and licensed the patent for our use.

The patent described an elegant solution to the midrange problem: a rectangular conductor.

Imagine a round conductor. Its outer diameter (surface area) is a fixed ratio with the inner diameter (core of the conductor). Any change in either effects the other in a predictably symmetrical fashion. Now imagine taking that same round conductor and flattening it into a thin sheet or rectangle. The amount of surface area has now increased dramatically, while the overall gauge or amount of material remains identical. Essentially, what you now have is a fixed core size with a variable surface area and this was exactly what our engineering team was looking for. We could now control the exact amount of skin effect we

needed without changing the core of the conductor. All we had to do was flatten the round conductor as much or as little as our design dictated to achieve the perfect blend of surface area to conductor core.

The results were spectacular. The mid-range performance of connected equipment had a bloom and openness that we had never experienced before in all our years of building high-end power cables. Truly, this was the major breakthrough in these exceptional cables; midrange performance better than anything we had ever experienced before.

The next problem was even more difficult. The treble (high frequency) conductors had the same requirements as the midrange only magnified. Here we wanted almost no core and all surface area and because of construction requirements we wanted multiple treble conductors to be insulated. To handle this and then bundle the group we would need to have a round cable. How do we then get the increased surface area of a flat cable as well as reducing the core?

That was a big problem but we solved it using a variation on the midrange solution.

First we would create a very thin flat rectangular conductor which maximized the surface area and focused the power on the skin of the conductor. Next, we formed the flat conductor into a hollow spiral tube and then extruded a PE foam jacket around the conductor and bundled multiple strands together to form the treble conductor.

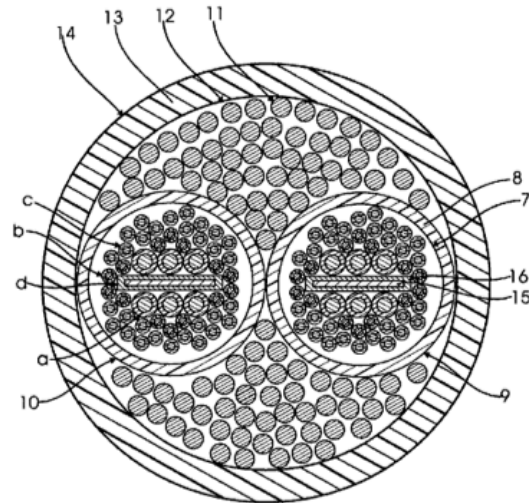
The use of PE foam around these conductors was very important. PE foam has a relatively high dielectric constant (compared to air) which means it will constrain the electric field close to the conductor itself. By constraining the electric field the energy of this conductor is held closely and will lower the chances of interfering with the other conductors and fields. Over the years we have found that this results in a very



(12) **United States Patent**
Lee et al.

(10) Patent No.: **US 6,969,805 B2**
(45) Date of Patent: **Nov. 29, 2005**

(54) STRUCTURE OF AUDIO SIGNAL CABLE	4,628,151 A * 12/1986 Cardus 174/114 R
(76) Inventors: Chang-Chi Lee , No.58, Shi-An St., Hu-Wei Town, Yun-Lin Shian (TW); Jay Victor , No.58, Shi-An St., Hu-Wei Town, Yun-Lin Shian (TW)	4,777,324 A * 10/1988 Lee 174/34 5,491,299 A * 2/1996 Naylor et al. 174/36 5,510,578 A * 4/1996 Donlavy 174/128.1 5,516,986 A * 5/1996 Peterson et al. 174/113 C 5,976,070 A * 11/1999 Ono et al. 600/110 6,194,663 B1 * 2/2004 Friesen et al. 174/110 R 6,388,188 B1 * 5/2002 Harrison 174/27 6,495,763 B1 * 12/2002 Eichmann et al. 174/113 R
(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 111 days.	* cited by examiner
(21) Appl. No.: 10/619,441	<i>Primary Examiner</i> —William H. Mayo, III
(22) Filed: Jul. 16, 2003	(74) <i>Attorney, Agent, or Firm</i> —Trojan Law Offices
(65) Prior Publication Data	(57) ABSTRACT
US 2005/0011667 A1 Jan. 20, 2005	An audio signal cable, the features of which are that the audio signal cable has arrayed solid and tinsel wire conductors. After each of the conductors are insulated and banded, they are placed into a surrounding insulation. The solid conductors are of a circular and a flat, thin shape. The solid conductors are of differing larger and smaller diameters and, furthermore, disposed in unequal quantities.
(51) Int. Cl. ⁷ H01B 7/00	
(52) U.S. Cl. 174/110 R ; 174/113 R; 174/115	
(58) Field of Search 174/36, 110 R, 174/113 R, 115, 116, 117 F, 117 FF, 114 R	
(56) References Cited	5 Claims, 2 Drawing Sheets
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open sounding presentation, especially in higher order musical harmonics like those produced by a piano or acoustic guitar.

Using these techniques and this unique geometry we then proceeded to design the conductor configuration for each of the 4 cables in the line. We could now vary the wire gauges, the skin effect and core sizes for the midrange and the surface area for the treble to achieve the perfect blended and balanced cable within each of the constraints of all 4 models.

Shielding

Shielding a cable means that you place conductors around the entire cable to pick up any electrical noise from within the power cable or from the outside of the cable and carry the noise off to ground. This is important because the equipment you are connecting to generates noise on the power line which is injurious to surrounding equipment as well as keeping extraneous noise from getting into the power cable. Good shielding is a requirement for any power cable in a high-end system.

The design philosophy, with respect to shielding in the AC Series can be summed up in one word: quiet. We have found over the years that good shielding means a quiet presentation without an overriding bright “hash” accompanying each note of the music. By eliminating internal and external noise through well shielded power cables, connected equipment is remarkably free from the bright hardness associated with most power cables and delivery systems. This phenomena is not readily apparent until you listen to a component with and without this noise. A high-end system powered through well shielded cables, vs. the same system with poorly shielded cables is remarkably easy to identify with a short listening session.

In the PerfectWave AC Series, we do not rely on a single shield as found in most power cables. In fact, we use a double shield in the AC3, AC5 and AC10, with a quad shield in the AC12. This extraordinary level of shielding raises the performance of connected equipment up to perfection levels.

Conductor materials

One of the other most important considerations in developing a high-performance power cable, is the grade of copper to be used for the conductors.

If you look at the conductor materials available, typical high purity electrical-grade copper has approximately 1500 grains (or crystals) per foot. The boundaries of all these crystals must be crossed by the AC in the process of being transmitted across the cable. It is not hard to imagine that crossing all of these boundaries must cause some sort of loss and/or distortion of the signal. This may be similar to the effects of stranded wire, and it does seem to cause the same sort of audible distortion perceived in a power cable as a “gritty” sound.

The next grade above normal high purity electrical-grade copper is called OFC (Oxygen-Free Copper), or sometimes Oxygen-Free High-Conductivity (OFHC) copper. This term is a bit misleading, because OFC

copper is not really oxygen free. It is cast and drawn in a process where oxygen content is limited, thus reducing the formation of copper oxides, which lead to a larger number of crystals. The oxygen content for OFC is typically in the range of 40 PPM (parts per million), while normal grade copper is approximately 235 PPM. The end result is that OFC has approximately 400 grains or crystals per foot, as opposed to 1500. There are significantly less boundaries for the signal to cross, and thus the signal is degraded far less. This is a substantial improvement over normal high-purity electrical wire. OFC and OFHC copper materials are not all the same, however, and these are much-abused terms. The oxygen content does vary, and it is a range, rather than a finite definition. Performance levels do vary with the quality level of the material, and not all "OFC" copper sounds or performs at the same level.

The next higher grade is an elongated grain copper sometimes called "linear-crystal" (LC-OFC), "mono-crystal", or "long-grain" copper. These coppers have been carefully drawn in a process that results in only about 70 grains or crystals per foot. Since OFC copper typically has approximately 400 grains per foot, this is clearly an improvement, and the reduced amount of crystal boundaries causes far less audible "grit".

The best level of copper for audio and power applications would obviously be totally free of crystal boundaries.

PCOCC

Professor Atsumi Ohno began the study of the solidification of metals in the mid 1960's, and published his landmark book, *Solidification; The Separation Theory and its Practical Applications*, in 1984. In this book, Ohno describes his many theories and concepts regarding the processing and solidification of molten metals, and the resulting crystal structures. He goes on to describe his unique process for casting metals with virtually no crystal structure, the O.C.C. process. This concept was first conceived of in 1978, and utilizes heated molds in a continuous casting process. Eventually, international patents were granted for O.C.C. (Ohno Continuous Casting).

The copper produced by this method is small rods of O.C.C. pure copper, from which wire can be drawn and which can have single copper grains of over 700 ft in length. A Japanese manufacturer is currently using this process and produces O.C.C. under the trade name PCOCC (Pure Copper by Ohno Continuous Casting).

In the PerfectWave AC Series, the AC3 uses OFC for its conductor. The AC5 utilizes LC-OFC and both the AC10 and AC12 use PCOCC for their conductors.

The use of each material gives us a different balance when used to power a system. It is necessary to tune each of the 4 cables to maximize their performance based on their overall wire gauge and copper type.

Conclusion

The PerfectWave AC Series of power cables is the finest power delivery system we have ever built in the over two decades of designing power cables for high-end audio and video systems.

Achieving the remarkably well balanced performance of each cable within the AC Series remains the hallmark of our achievement in this complex design exercise of creating world class AC power cables.