Tech Notes

May 2017

Pro iESL

Pro iESL

An Exacting Energiser

Part one.

A little background

The Pro series iESL is the best way of driving electrostatic headphones. We are confident that the iESL Pro *driven by either* the iCAN Pro or your existing amplifier can go toe-to-toe with the best amplifiers out there for electrostatic headphones. Its defining characteristic is a transparency and an ultra-wide dynamic range that is totally natural.

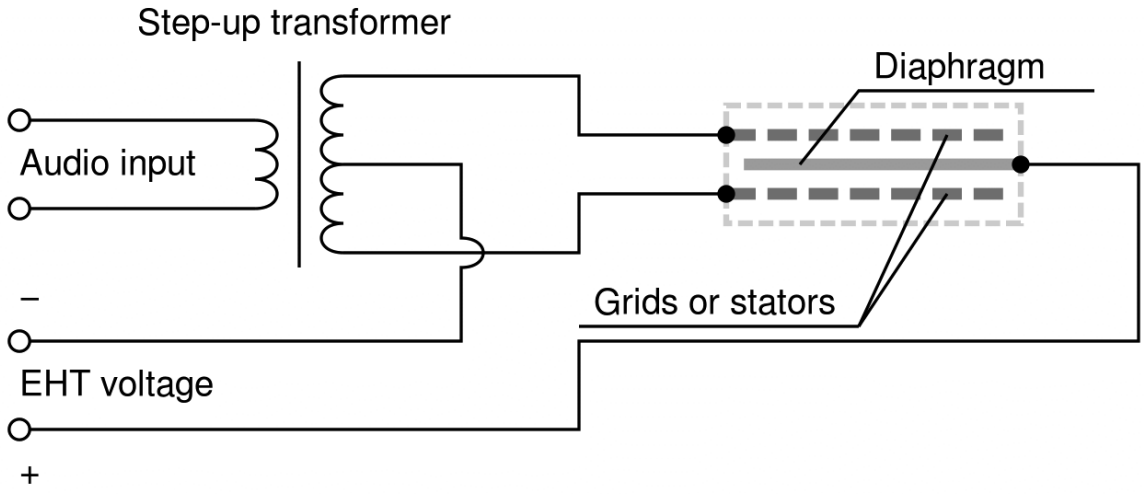
Why do I need an electrostatic headphone amplifier?

We have quoted from Wikipedia:

ELECTROSTATIC DRIVERS CONSIST OF A THIN, ELECTRICALLY CHARGED DIAPHRAGM, TYPICALLY A COATED PET FILM MEMBRANE, SUSPENDED BETWEEN TWO PERFORATED METAL PLATES (ELECTRODES). THE ELECTRICAL SOUND SIGNAL IS APPLIED TO THE ELECTRODES CREATING AN ELECTRICAL FIELD; DEPENDING ON THE POLARITY OF THIS FIELD, THE DIAPHRAGM IS DRAWN TOWARDS ONE OF THE PLATES. AIR IS FORCED THROUGH THE PERFORATIONS; COMBINED WITH A CONTINUOUSLY CHANGING ELECTRICAL SIGNAL DRIVING THE MEMBRANE, A SOUND WAVE IS GENERATED. ELECTROSTATIC HEADPHONES ARE USUALLY MORE EXPENSIVE THAN MOVING-COIL ONES, AND ARE COMPARATIVELY UNCOMMON. IN ADDITION, A SPECIAL AMPLIFIER IS REQUIRED TO AMPLIFY THE SIGNAL TO DEFLECT THE MEMBRANE, WHICH OFTEN REQUIRES ELECTRICAL POTENTIALS IN THE RANGE OF 100 TO 1000 VOLTS.

DUE TO THE EXTREMELY THIN AND LIGHT DIAPHRAGM MEMBRANE, OFTEN ONLY A FEW MICROMETERS THICK, AND THE COMPLETE ABSENCE OF MOVING METALWORK, THE FREQUENCY RESPONSE OF ELECTROSTATIC HEADPHONES USUALLY EXTENDS WELL ABOVE THE AUDIBLE LIMIT OF APPROXIMATELY 20 KHZ. THE HIGH FREQUENCY RESPONSE MEANS THAT THE LOW MID-BAND DISTORTION LEVEL IS MAINTAINED TO THE TOP OF THE AUDIBLE FREQUENCY BAND, WHICH IS GENERALLY NOT THE CASE WITH MOVING COIL DRIVERS. ALSO, THE FREQUENCY RESPONSE 'PEAK' REGULARLY SEEN IN THE HIGH FREQUENCY REGION WITH MOVING COIL DRIVERS IS ABSENT. WELL-DESIGNED ELECTROSTATIC HEADPHONES CAN PRODUCE SIGNIFICANTLY BETTER SOUND QUALITY THAN OTHER TYPES.

ELECTROSTATIC HEADPHONES REQUIRE A VOLTAGE SOURCE GENERATING 100 V TO OVER 1 KV, AND ARE ON THE USER'S HEAD. THEY DO NOT NEED TO DELIVER SIGNIFICANT ELECTRICAL CURRENT, WHICH LIMITS THE ELECTRICAL HAZARD TO THE WEARER IN CASE OF FAULT.



Source: https://en.wikipedia.org/wiki/Headphones#Electrostatic

To put this theory into perspective with some figures,

Sennheiser HD800 dynamic headphones = 102dB/1V
Typical pair of electrostatic headphones = 102dB/100V!!!

Traditional headphone amplifiers do not deliver either the EHT voltage or the required audio voltage. So a special 'Energiser' is required to match the electrostatic headphones. Typically a maximum output of 300V is needed. This is equivalent to 300 Watt into a 300 ohm headphone load!

Hence, electrostatic headphones require:

- VERY high voltages – need 300V in an instant
- BIAS voltage – adjustable from 230V to 640V

There are two options to make such a product to 'energise' electrostatic headphones:

Product A: a dedicated high-voltage amplifier.
Product B: an Energiser, a solution which is almost opposite to a tube amp as it converts low-voltage to high-voltage.

In the real world, few amplifiers can deliver these levels of voltage output which is why an 'Energiser' is required to 'charge' electrostatic headphones. Some existing tube amplifiers (like the iFi RETRO Stereo 50) could be modified to drive electrostatic headphones directly and some solid-state high voltage amplifiers also exist, however the need for such extraordinarily high-voltages compromise the active 'direct high-voltage' of most amplifiers.

By comparison, an Energiser can use a standard speaker amplifier or a suitably powerful headphone amplifier (> 10V into 16 ohms or > 20V into 64 ohms are needed) and use transformers to produce the high-voltage required.

The iESL is the second type of a product: an Energiser. Yet the iESL is no ordinary Energiser. Each one of these three-core components were developed using the best classic *and* latest approaches with scant regard for cost, complexity or difficulty:

- The transformer
- The bias voltage generator
- The component quality

To give:

The Transformer – the 'sound' of the Energiser

Like a good chassis in a car, a transformer makes or breaks the Energiser. This is fundamental, simply because it is almost solely responsible for the 'sound' of an Energiser. Ideally a transformer would have no 'sound' signature of its own, but simply and transparently pass on the audio signal. In reality this is a challenging mandate.

A transformer is comprised of two parts, both of which in the iESL, have been executed very much with more than a nod to the 'money is no object' days of classic Altec and Western Electric design, materials and workmanship.

Since the golden age of stereo in the 1950s and 1960s, the art of making great audio transformers was mostly lost when tubes fell out of favour. At AMR/iFi, we retain this arcane knowledge and wish to carry it on well into the 21st Century. First with the AMR transformers, then we went onto the output transformers in the Retro Stereo 50. Now we have moved onto the iESL 'PPC' transformers.

To make these transformers, we had to source the required materials and implement a classic, yesteryear method of hand-winding transformers that is almost a lost art but absolutely worth the effort.

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1.1 The Core – the 'tone'

The iESL transformer core uses a mix of Mu-Metal (aka Permalloy) lamination and Grain Oriented Silicone Steel (aka GOSS). Most audio transformers for such higher levels and power restrict themselves to using steel.

https://en.wikipedia.org/wiki/Electrical_steel#Grain_orientation

+ GOSS handles high signal levels well, which is needed if we wish to produce 300V or even more.

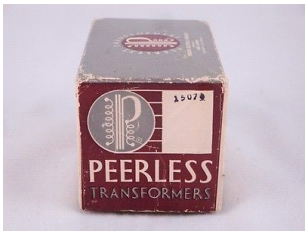
- GOSS has problems with hysteresis at low levels, causing loss of low-level detail. In some cases this 'simplification' of the music signal may be a desirable effect, however it is a clear and audible distortion.

Mu-Metal is a unique magnetic alloy with very different properties to GOSS:
https://en.wikipedia.org/wiki/Mu-metal

+ Mu-Metal/Permalloy is great for low signal levels (low-level resolution) but cannot handle high-level signals well. Mu-Metal based transformers are well known for their crystal clear sound, but generally cannot handle high-levels, restricting them mostly to use in microphone pre-amplifiers or for moving coil LP-pickups, where signal levels are measured in thousands of a Volt, rather than hundreds of a Volt.

- Mu-Metal/Permalloy requires heat treatment after being worked (e.g. being cut) to restore its magnetic properties. It is hugely more expensive than GOSS and in limited and forever dwindling supply as existing makers close up shop or are acquired and drop less profitable, lower volume products such Mu-Metal/Permalloy from their lines.

Combining the two materials in pinstripe fashion, a process pioneered by Peerless Transformers USA in the 1950s gives the best of both materials.



Peerless Transformers featured in the legendary Western Electric and Altec (“All Technical Services”) recording equipment from the golden age of stereo.

Getting identical laminations in GOSS and Mu-Metal/Permalloy is challenging, getting ultra-thin laminations such as we prefer to use, more so and then manually and individually assembling each core with different materials in a repeatable pattern has to be done by hand. Arduous? Yes, but worth it.

1.2 The Winding – ‘Voice of the Transformer’

While a good core is the key to making a transformer that has good dynamics and correct tone, the winding must be equally considered. Due to many limiting factors, making a transformer with a wide bandwidth and low distortion is very challenging. The winding structure determines the bandwidth of transformers. Typically winding audio transformers is a compromise between low frequency cut-off, low frequency distortion and high frequency cut-off. These three elements tend to form one of the classic "choose any two" triads, especially for classic ‘layered’ construction transformers. Often transformers have a high frequency cut-off (-3dB) barely higher than 20kHz and low frequency cut-offs barely below 20Hz.

An Energiser using such transformers is likely to exhibit a muffled top end while bass is compromised by the lack of really low cut-off and excessive phase-shift in the audible range. As an absolute minimum specification, we targeted < 10Hz – 40kHz, -3dB, which is required by the JAS ‘High-Res’ logo, which we strive to earn with all our products.

To attain such performance, some rarely used techniques were employed to sidestep the ‘choose any two’ limitations for the iESL.

The key is the use of Scheibenwicklung (disk-winding)...

The Scheibenwicklung is also quite old, German patent DE861406 C issued to Siemens GMBH Jan 5, 1953 with a filing date of May 14, 1943. (http://google.com/patents/DE861406C?cl=ko) covers this.

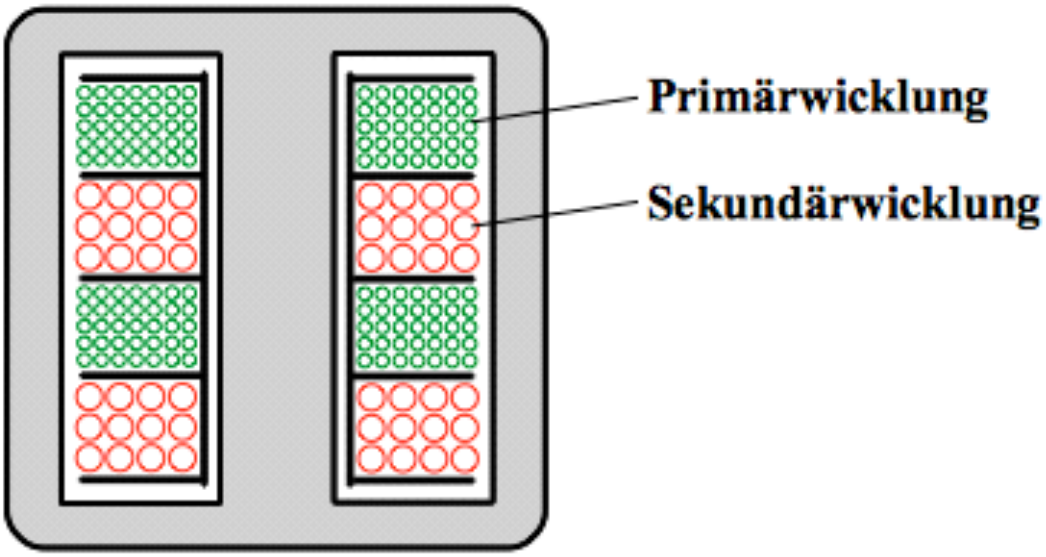


Bild 15-9: Transformator mit Scheibenwicklungen

The much more common layered winding is not able to offer as wide bandwidth.

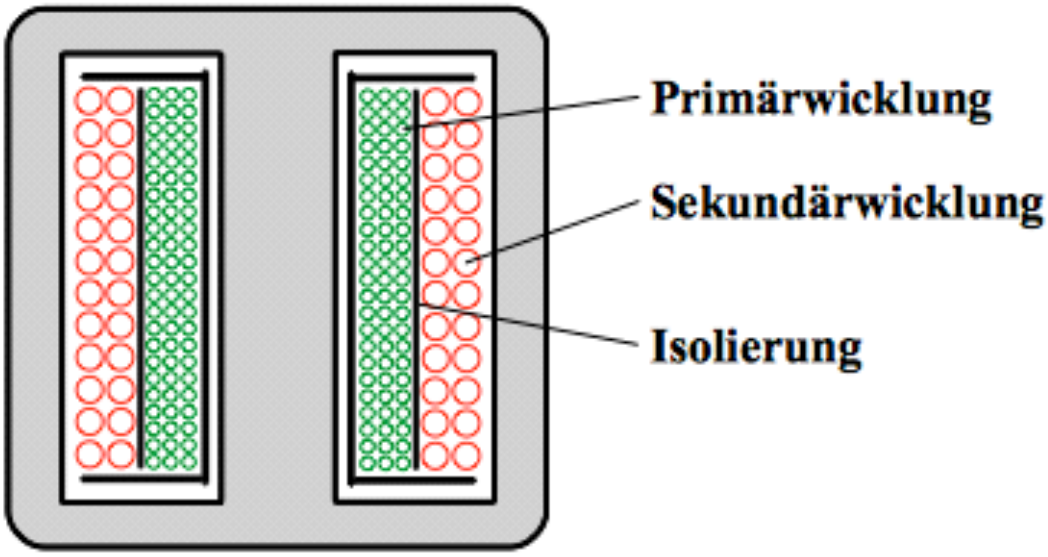


Bild 15-10: Transformator mit Zylinderwicklungen

Transformer Illustration from here: http://elektronik-kurs.net/elektrotechnik/transformatoren/

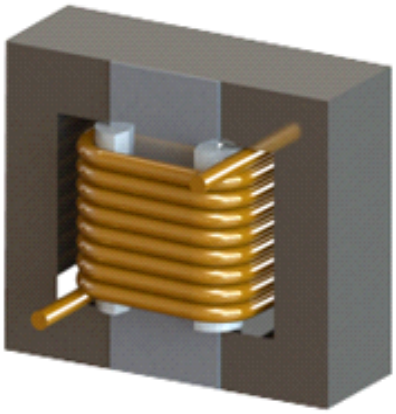
Transformers in the iEnergiser are unique in combining Scheibenwicklung and layered winding in a complex interleaved pattern to achieve results that considerably exceed either technique. The design of such transformers is mostly an extinct art, with virtually no text remaining (never mind in print) and few people who still have the know-how. And manufacturing of such designs is orders of magnitude more challenging than generic transformers.

Our transformers match and exceed the standards set by Siemens (Germany) and Peerless (USA). With a bandwidth of < 5Hz to > 60kHz (-3dB), transformers in the iESL *far exceed* the requirements of even the JAS High-Res Logo.

To recap, in order produce high-voltages required by electrostatic headphones, the Pro iESL employs custom-made **Pinstripe Permalloy Core Transformer (PPCT)** of the highest quality:

- Ultra-wide bandwidth signal: attains <10Hz all the way up to 60 kHz.
- Perfectly linear: from low through to high signal levels.
- The extremely critical core of the transformers is a GOSS/Mu-Metal hybrid. This reduces distortion dramatically, when compared to traditional cores, be they GOSS, amorphous iron or similar materials.
- In order to combine a high step-up ratio with good behaviour without excessive resonances or bandwidth limitations our custom transformers use a complicated multi-section winding with both vertical and horizontal sectioning. Extremely thin wire must be wound precisely and tightly to create the performance required.

Combining this complex winding with an exceptional core produces a transformer that handles ALL levels without distortion drawbacks as well as offering a completely flat frequency response without colorations well beyond the audio band.



In terms of performance, only such an exceptional transformer can approach and even exceed the best transformer-less amplifiers.

Part 2: Bias Voltage

In addition to the actual music signal, a pair of electrostatic headphones requires the so-called “bias voltage.” Whereas so-called dynamic headphones have a static magnetic field which provides the ‘bias,’ in the case of electrostatic headphones, a static electricity field is needed. It is important that this voltage is both extremely clean and precise.

Exceeding the bias voltage significantly (even only due to high mains line voltages) can damage the electrostatic headphone, noise on the bias voltage will modulate with the music signal.

The bias circuit itself with the headphone forms a low-pass circuit that is effective in suppressing supersonic noise (by at least 100 times), however low-frequency noises pass without any reduction.

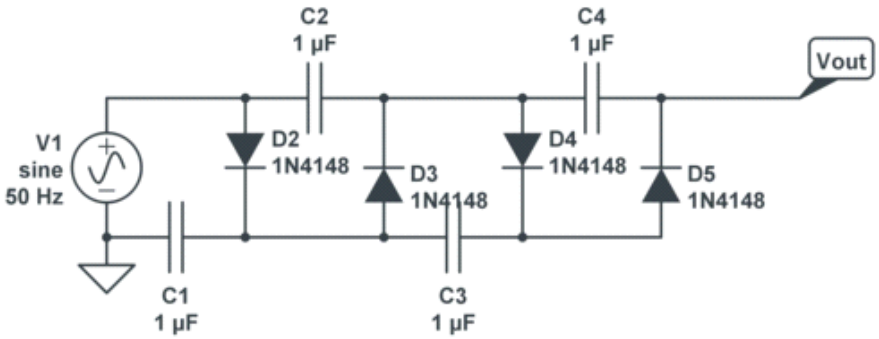
This makes clear that the bias circuitry for electrostatic headphones is ‘quite’ critical, yet in most Energisers and dedicated ES headphone amplifiers, one might be forgiven for considering the bias circuitry was a mere afterthought.
There are two common approaches to offering bias voltages:

- **High Voltage Transformer & Rectification**: Custom high voltage (appx 410V for Stax Pro Bias) transformers provide 50/60Hz AC which is rectified. These are custom transformers with very high voltage windings which are unavailable off the shelf. They are very rare and are seldom seen, even on electrostatic speakers!

- **Cascade rectifier**: achieves high voltages but is very noisy. The noise can be filtered but this is not preferred as some residual noise always ends up in the music path which is sub-optimal.

Background to Biasing Voltages

The Cascade rectifier circuit is perhaps the most common yet is also the most compromised. The most common approach to the bias voltage is created using 50/60Hz mains power and a so-called Villard or Greinacher cascade rectifier (which is also sometimes called a Cockcroft-Walton voltage multiplier).



This circuit can deliver very high voltages using rather generic and inexpensive components, but its operation is noisy.

Given the low frequencies of the AC used, large value capacitors tend to be needed, usually requiring rather non-linear electrolytic capacitors, which have high leakage currents and so the cascade rectifier must operate constantly to keep the Bias Voltage from dropping.

To us, both approaches were unacceptable.

We decided to discard all existing solutions. We went with a third option. While the Bias Voltage is high, there is almost no current draw.

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Option 3: The Capacitive Battery Power Supply

Listening to a vintage battery-powered Energiser from our collection of eclectic and *sui generis* HiFi collection, we noticed that once the power was turned off, the electrostatic headphones kept playing for many minutes just on the retained charge in a small capacitor. More apparent was that sound quality was noticeably better as the primitive switched mode step-up circuit was off. This was a real "eureka!" moment.

The 3rd solution

We decided to use a large battery of capacitors, using high-grade Wima Germany made film capacitors rated at 1,000V DC. Then the aim was to charge them up once to the required voltage and to then turn the charger circuit off entirely, leaving the capacitor bank to 'float' at the required bias voltage. This gives an essentially perfect bias voltage source, pure static electricity, no electronic noise whatsoever at any frequency. Talk about killing birds with stones!

The Design

In order to provide this one time charge, we employ a very high-frequency switching system (@ 750kHz). It uses a tiny, fully-shielded transformer and exotic ultra-fast high voltage rectifiers. More crucially, this system shuts down completely as soon as correct bias voltage has been established in the capacitor bank. This also means that the bias voltage is precision regulated to a small fraction of 1V to the official bias voltage, no changes in mains voltage or other factors will cause the bias voltage to shift.

As some minor discharge occurs even through air, the charging system checks the capacitor bank every 30 seconds attempting to recharge the capacitor bank. If the bank is still fully-charged, the process usually takes a few millionth of a second

(microseconds) as usually one or two switching cycles suffices to replenish the lost charge. Then the switching system is again off completely.

Any noise that this system creates is confined to medium frequency radio bands for the infrequent short durations during which it is active. In practice, over 99.999% of the time the charging circuit is completely off.

The practical outcome is in effect a perfect high-voltage battery to provide the bias for electrostatic headphones. Two completely separate and independent bias circuits are employed, one for the 230V 'normal' bias and another adjustable, to cover a wide range of modern electrostatic headphones.

This is all deployed in a totally separate circuit which is standalone and is not in the music path at all.

Using this unique solution, the *Capactive Battery Power Supply* in the Pro iESL is able to provide bias voltages for all known electrostatic headphones across an incredibly wide range:

Bias voltage usage:

230V (Normal)	"normal Bias" Stax ESHP	
500V (Custom)	Sennheiser Orpheus HE-90	
540V (Custom)	Sennheiser HE-60	King Sound KS-H2/3/4
580V (Pro)	"Pro Bias" Stax ESHP	
600V (Custom)	KOSS ESP/950, Jade	
620V (Custom)	Optional	
640V (Custom)	Optional	

While this is an uncommonly comprehensive wide range of adjustability, compared to other Energisers, the iESL approach to bias voltage is unique.

Part 3: Audiophile parts, unparalleled signal performance

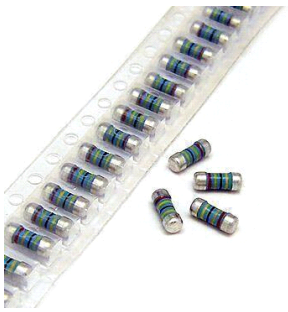
In order to select input signals and to switch speaker connections, high-grade signal relays are used.

WIMA capacitors

These 1,000Volt rated capacitors are from Germany. The key is the very high insulation resistance and minimal current leakage, as any such leakage causes self-discharge. The whole capacitor pack has around 35,000,000 kOhm insulation resistance, which means that self-discharge time (to 30%) is around 100,000 seconds or 27 hours.

Hence, they are perfectly suited for the capacitive battery power supply of the iESL.

Vishay MELF resistors



MELFs offer superior SMD resistor performance in terms of accuracy, stability, reliability, and pulse load capability. The cylindrical construction of MELF devices provides an optimal power rating and pulse load capability. MELF are more complex to make and so cost more. When assembling PCBs MELF need special machines and treatment. Hence they are seldom used.

Gold-plated silver contact relays

The entire signal switching for the input selection utilises gold-plated silver contact miniature relays, filled with an inert gas. This makes sure the contacts will be as new for many years to come.

Sealed-silver alloy contact relays

The speaker connections are switched using sealed silver alloy contact relays for minimum impact on the sound quality of the speaker path.

We hope this outline has offered a small insight into the makings of the Pro iESL. Simple in theory but complex is practice.

There you have it, the iESL. It is one very special Energiser unit for Sennheiser Orpheus, Stax electrostatic ‘Ear Speakers’ and dynamic headphones.

We thank you for reading this and your interest in the history and development behind the Pro series iESL.

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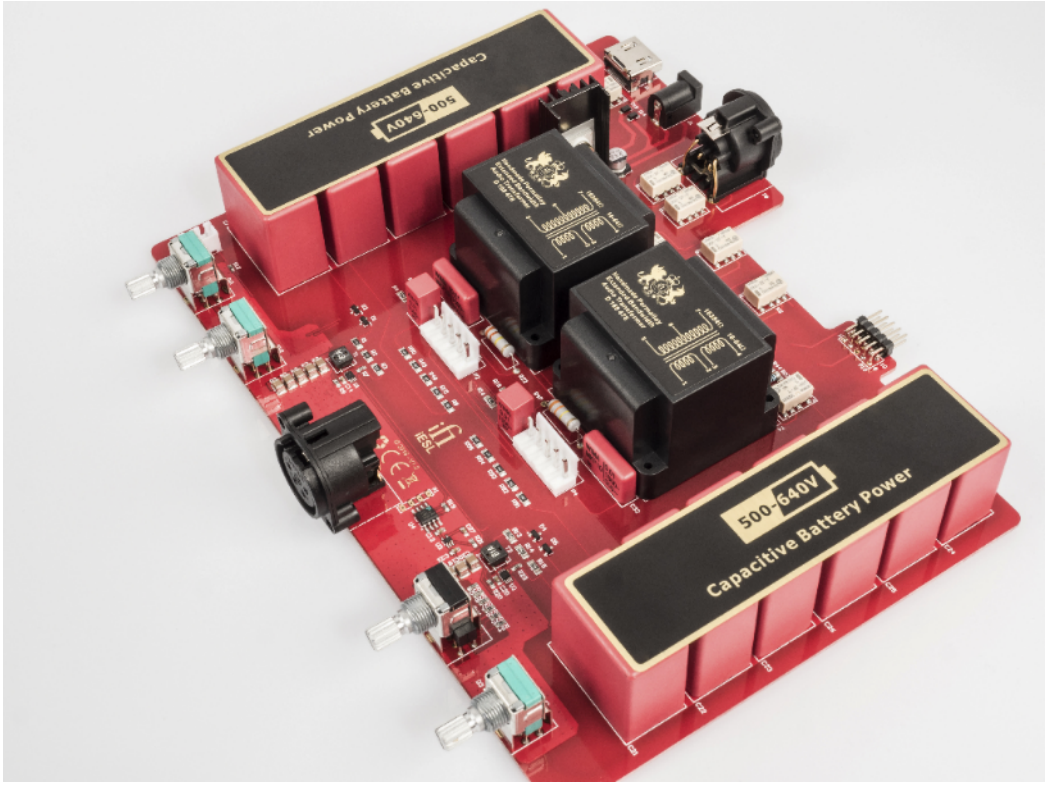

Addendum notes on Pro iESL use with Pro iCAN

Most ESHP are very inefficient. Due to the limited Voltage handling and the low sensitivity ESHP generally do not play very loud, especially compared to traditional dynamic headphones. So do not expect them to go as loud as dynamic headphones.

Depending on the impedance control setting the Pro iCAN and Pro iESL combo can deliver between 320V RMS (910V PP) using the 64/96 Ohm setting and up to 640V RMS (1820V PP) using the 16/24 Ohm setting.

These are very high voltage levels and may exceed the rated limit of the ESHP. Please confirm with the manufacturer of your ESHP what levels are allowed and if any doubt only use the high impedance settings.

When using the iESL with Pro iCAN remember to keep gain, X-Bass & 3-D Sound settings moderate. Maximum gain is recommended at 9dB, 3D only at the lower settings and the same for X-Bass, otherwise the stress on both amplifier and headphone may be excessive.

Under the above conditions, the volume on the Pro iCAN should be able to be advanced to maximum (using an iFi DAC) without risk of protection circuitry engaging or damaging ANY ESHP as long as the Pro iESL impedance setting is 64Ω or 96Ω.

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About iFi
iFi Audio is headquartered in Southport, UK. It is the sister brand of Abbingdon Music Research (AMR). They respectively design and manufacture portable and desktop 'ultra-fidelity' audio products and high-end audio 'home-based' components. The combined in-house hardware and software development team enables iFi Audio and AMR to bring to market advanced audio products.