

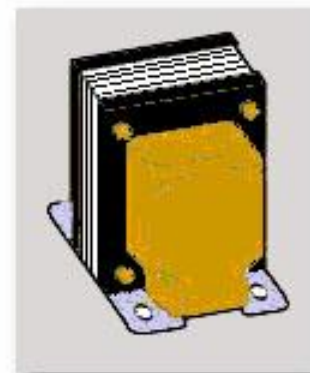
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## **The High-End Mythology of the Toroidal Power Transformer**

If you look at the AC power transformers used in most high-end audio equipment these days, you will find that a very large majority are toroid transformers. These donut-shaped transformers seem to have taken the high-end industry by storm. Their major advantage is that they do not radiate much of a magnetic field--a very useful property. Dealing with stray magnetic fields from EI-frame transformers (non-toroid) inside a high-end component is not a trivial undertaking. While toroidal transformers have one significant advantage regarding radiated magnetic fields, toroids have a number of "problems" that severely limit their performance in high-quality audio equipment. We'll try to help you understand what these problems are and show you how another kind of transformer, the EI-frame transformer (that's a capital I, "eye," not a lowercase I, "el") can be a superior performer if designed, manufactured and installed properly.

### **What's an EI-frame transformer?**

EI-frame transformers have a large laminated section that looks like an E before it is assembled. Wire is wound around the center leg of the E through the gaps. When the winding is complete, a laminated I section is installed over the ends of the E. The two pieces of the core or frame of this type of transformer give it beneficial "air gaps" which act as pressure relief valves for excess magnetic flux. Winding on the E frame is relatively easy. The illustration to the right is a representation of an EI-frame transformer. The laminated EI core is in the center. The brass colored end is a "bell" covering the windings. In the gray metal tabs on the bottom are mounting holes to hold the EI-frame transformer to the chassis of the component. The brass colored bolts go through the laminations and hold the separate E and I pieces together.



### **What's a toroidal transformer?**

A toroidal transformer has a round core. Like all transformers, the core is laminated, or made of many layers. In the case of a toroidal transformer, the core resembles a bunch of sheet metal Os stacked on top of each other forming a hollow cylinder. Winding a toroidal transformer is trickier because each time the wire is wrapped around the core, the wire has to be passed through the hole in the center. When a toroidal transformer is finished, it has wire wrapped completely around the core leaving the outside layers of windings relatively vulnerable to damage. Because of this, toroidal transformers are usually mounted to the chassis by putting a rubber mat on both sides of the transformer and running a bolt through the center hole with what looks like a giant washer on top of the transformer. Tighten the nut onto the top plate and the transformer is squeezed between the two rubber pads and held in place.

There are things that can be done to toroidal transformers to reduce some of their inherent problems, but I have yet to see one of these "correct" toroidal power transformers used in a high-end audio component.

Manufacturing a "correct" toroidal power transformer is not a trivial task. Toroids are already more expensive to make compared to EI-frame transformers because each toroid has to be wound one-at-a-time while EI-frame transformers can be made in batches on highly automated winding machinery. However, precision winding an EI-frame transformer by hand, very carefully, using bi-filar winding techniques can produce some stunning transformer performance results.

### **Some background about how AC power is delivered to residences (120v used in this description, 208/240 is similar)**

When AC power is transmitted across long distances, high voltages increase transmission efficiency and decrease the size and weight of cables needed to carry the power. However, high voltages in the home are quite dangerous so power companies build sub-stations to reduce the voltage levels for residential and light business use. In the US these substations produce three-phase electrical power. Two of the three phases are what is typically delivered to residences. These electrical phases each carry (nominally) 120v rms AC referenced to the neutral wire... all three phases use the same neutral wire/connection/reference. When two phases are supplied to a home or business, you have three wires coming into the house. One of them is neutral. You can connect the two 120v lines to a single electrical outlet and get 208/240 AC volts which is used to power electric dryers, electric ranges and stoves, electric water heaters and other heavy duty electrical appliances. But most of the connections in your home are 120-volt connections using one of the two phases plus neutral. The ground wire for your home is created right at the site of your home. Somewhere on the property, an electrician has driven a large copper rod directly into the ground (the dirt). A heavy ground wire is connected to this buried copper rod and run to the electrical distribution panel.

The thing to remember about this three-phase and two-phase power delivery system is that the loads on each phase must remain balanced or you can get a DC offset to the AC voltage. If power becomes unbalanced in any one phase, a DC offset appears in your AC power. These DC offsets can be transient or long-term. You still get the 120 (nominal) rms volts, but instead of it being a sine wave with positive peaks of about 170 volts and negative peaks of -170 volts, the sine wave is shifted up or down. A +5-volt DC offset would result in positive peaks of 175 volts and negative peaks of -165 volts (approximate voltages). A -6-volt DC offset would result in peaks of +164 and -176. All because the power becomes unbalanced, *i.e.* there is more load on one or two phases than on the remaining phase. These DC offsets can very dynamic, changing constantly as residences and businesses consume power and turn machinery on and off. Some of the offsets cancel each other out, resulting in no DC offset, but it is not terribly unusual to have transient DC offsets in power delivered to homes in the US. In Europe, depending on the country, some power grids are owned by the country and are actually running at full capacity or even higher than full capacity. In those situations, the potential for DC offset to exist in the power delivered to residences is quite high.

### **Two transformer types versus DC offset**

What does DC Offset have to do with the AC Power Transformer? Everything! You see, the toroid transformer is very intolerant of DC offset being present at the input (primary winding). In fact, if there is any DC at all in the AC power supplied to the typical AC Power toroid transformer, the laminated metal core of the transformer "saturates" and the transformer no longer operates as designed. The result is often high levels of audible noise from the transformer as well as very high levels of noise getting into the power supply of the component.

When an EI-frame transformer is used, the DC offset problem disappears. The EI-frame transformer continues to supply AC power of the proper voltage with all the noise elimination capabilities designed into the EI-frame transformer still operating perfectly. Industry outside of high-end audio has not widely adopted the AC toroid power transformer because of these very problems. The majority of transformers in general use outside of high-end audio equipment are actually EI-frame transformers.

The main advantages of EI-frame transformers over toroidal transformers are: less susceptibility to core saturation from DC offset; air gaps which act as pressure relief valves for high density magnetic flux in the core. Saturation of the transformer core results in an energy build-up in the core of the transformer. Toroid transformers are wound with the core completely covered by the primary and secondary wires. The toroid core is completely isolated from ground. In the EI-frame transformer, however, a significant portion of the core is external and is attached directly to the chassis of the equipment it is installed in. This gives any energy build-up in the core a direct path to the chassis ground of the component. The other advantage EI-frame transformers have is the small air gaps that are present because of the gaps present when the two parts of the frame/core are put together. These air gaps act as pressure relief valves for the magnetic flux in the core further enhancing the transformer's resistance to core saturation. You can have an air gap in the core of a toroidal power transformer, but this requires machining a gap perhaps 0.020" wide, about the thickness of a sheet of paper. This is not a trivial task and adds significantly to manufacturing cost of the toroid transformer. It is very rare to encounter toroid transformers with air gaps because of the cost and difficulty of machining such a thin slit across the laminations that make the metal donut. These are two of the reasons EI-frame transformers, when properly designed, can provide better audible performance in your audio components.

### **What's the catch?**

It seems like an EI-frame transformer ought to be a 100% shoe-in for high-end audio components, but there is a "dark side" to the EI-frame transformer. They radiate a rather significant magnetic field from the exposed windings (which are sometimes covered by rounded metal end bells). Low level audio signals such as those found in preamplifiers and gain stages prior to the output stage of amplifiers are small enough in magnitude, that passing them through a strong magnetic field would induce hum in the audio signal. In a preamplifier, this is easy to avoid. Put the power supply in an external enclosure as many preamp manufacturers do, especially those who use EI-frame power transformers. In an amplifier, the answer is to "aim" the transformer correctly. There is a big "shadow" in the magnetic field where the laminated plates are...the magnetic field is strong only outside the end-bells of the transformer. Aim the EI-frame transformer so that the core points towards the audio signal processing and so that the "bells" point to the sides and the radiated magnetic field won't bother the audio circuits inside the amp. But putting an EI-frame in a tightly packed multi-channel amp or receiver is just about impossible...there just isn't enough room to stay away from the radiated magnetic field. In those applications, you will almost always find toroidal power transformers. You can jam a toroid right into the middle of five amplification channels and have no problems from magnetic fields. Magnetic shielding for an EI-frame transformer is also possible, but it tends to be expensive and heavy.

Another minor catch is that EI-frame transformers tend to be up to 50% heavier than a toroidal transformer of similar power capability. This is something to take into consideration, but in high-end audio components, the added weight would not be that important in most cases.

## Why lavish so much attention on the transformer?

When you look realistically at what happens in an audio component...you know the answer. The signal leaving the component existed only as AC power from your wall outlet only milliseconds before it is on the way to the next component or to the loudspeakers. AC power is the raw material for the output of the component. Make beer, wine, scotch or bourbon with bad water and you get a bad product. Make an audio component with a generic off-the-shelf toroidal transformer and you are going to get a generic sounding component. It won't be terrible, but it will fail to scale the heights of what is possible.

## So an EI-frame transformer is always better than a toroidal transformer?

Hmmm. Good question. I am tempted to say "yes" because really excellent toroidal transformers are apparently difficult, if not impossible to purchase off-the-shelf. However, finding great EI-transformers is no walk in the park either. But in general, being able to connect the core of the EI-frame transformer electrically to the chassis of the component and the air gaps created by the two-piece laminated core give even off-the-shelf EI-frame transformers some performance capabilities beyond what you can get from off-the-shelf toroidal transformers. If you know your magnetic theory (or your transformer vendor does), there are additional winding tricks that give EI-frame transformers 20dB to 30dB more noise rejection than typical toroidal transformers. This is very significant. 20dB less noise is 1/100th of the noise of the "reference" level. 30dB less noise is 1/1000th of the "reference" noise level. You might be able to find a toroid manufacturer who could do the custom winding, add an air gap and attach a ground wire to the core. You would pay two to three times the cost of an off-the-shelf toroid to get that level of performance. But you sure won't find a toroid off the shelf that performs as well.

I've been lucky enough to speak to a variety of high-end manufacturers about AC power, transformers, and component design. Conversations with Richard Vandersteen, Mike VansEvers and Emil Rotar (Warner Imaging) have been most illuminating. Years ago, I never really gave power transformers much thought. The assumption was that because so many high-end manufacturers were using toroidal power transformers, toroids must be demonstrably superior. Imagine my surprise when I started noticing that many of the best sounding components I've experienced in my system have all had EI-frame transformers. Coincidence? I might have thought so before finding out so more about power and transformers. Now I'm convinced that cleverly done EI-frame transformers could/should give us better sounding high-end audio components.

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