Shortform Introductory Article

The Audio Note™ Group C, Double C-Core Output transformers
Why Does Audio Note™ Choose Double C-Cores Rather Than I-E Core?

This is an area of very little understanding in the modern audio industry and as a result much controversy, so Andy Grove and I would like to give at least some background as to why Audio Note's best transformers use C-cores and always will do, despite cost and availability problems.

Basic (very) domain theory tells us that magnetic steels function by two main processes, domain growth and domain rotation.

Under low magnetisation, the field domains, which are oriented in the direction of the applied field, grow at the expense of their non-oriented and anti-parallel neighbours, this low field domain growth is generally reversible if the field is removed.

Under a medium applied field again domain growth is the predominant factor. However there will be some non-reversible growth of the domains, and a reverse field is required to return them to their original state.

Under a large magnetisation field those domains, which were not oriented in the direction of the applied field start to rotate towards that direction. Eventually all of the domains are pointing in the direction of the applied field and saturation is reached.

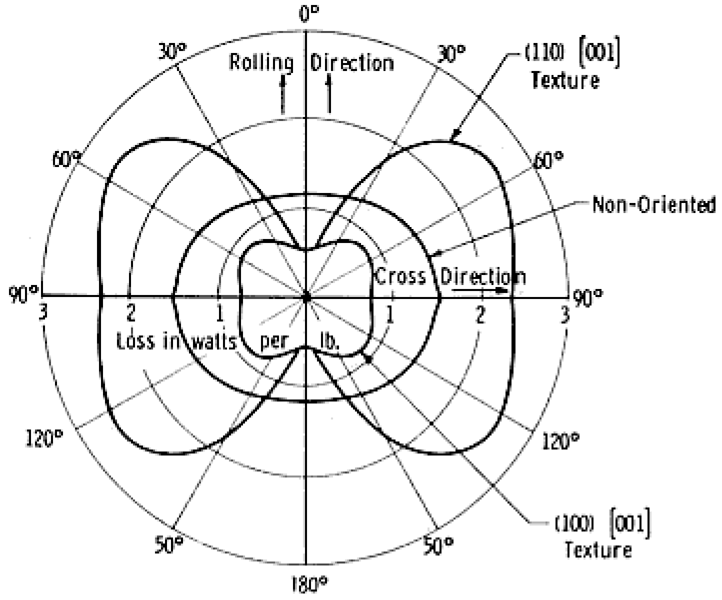
This neatly explains the familiar shape of the B-H curve and hysteresis loop.

Essentially iron crystalises in a body cubic form and the domains are oriented parallel to the edges of the crystal, therefore an iron crystal will be easier to magnetise if the applied field is parallel to an edge, and will be most difficult to magnetise in a diagonal direction across the cube.

In a non-oriented material the crystals and the domains are oriented randomly, therefore it will magnetise much the same in any direction. However no direction is aligned with the preferred direction of all of the crystals, and a lot of the crystals will be oriented in the worst direction.

Therefore permeability is low and losses are high. The hysteresis loop will be wide and rounded. In a singly oriented steel (M4 etc, there are cubic oriented types which we use as well) the crystals are oriented so that two of the faces are perpendicular to the strip rolling direction, two of the edges are parallel to it and the other edges are at 45 degrees to the strip surface. In other words the plane of the strip cuts the diagonal of the faces, which are perpendicular to it. This means that the material is very easy to magnetise by a field parallel to the strip rolling direction as the domains are facing in that direction.

This makes for a material with a high permeability, low losses and a narrow rectangular hysteresis loop when the field is in the strip direction. But it also means that a field in any other direction in the plane of the strip will be trying to magnetise the crystal in it's worst possible mode. The highest losses always occur at approximately 45 degrees to the rolling direction, in the plane of the strip.



This diagram shows the magnetization behaviour of GOSS and non-GOSS strip relative to rolling direction The I-E Core

Now, laminations are punched out of a steel strip such that the “arms” of the E point in the strip direction, however the back of the E is perpendicular to the rolling direction. The I is punched so that it’s longest side is parallel to the rolling direction. This of course means that with an I-E laminated transformer the flux has to curve round, across the grain at the corners, both at the junction of E and I and at the back of the E, and travel perpendicular to it across the back of the E.

In addition I-E laminations generally have whopping great holes punched just where you don’t want them. This means that a stack of grain oriented laminations ends up with better properties than a non-oriented stack but not by much. Quite serious curvature of the B-H curve starts to appear at around 1.2T to 1.3 T (Tesla) even though true saturation doesn’t occur until about 1.6T to 1.8T. The C-Core.

Enter the C-Core, as the C-Core is wound out of the strip the flux always traverses the preferred direction. This means that a C-Core remains linear almost to saturation and then hits a brick wall around 1.8T maybe a bit more. The losses are much lower as well, and that translates into lower distortion as the hysteresis loop is narrow and straight sided. Let’s say that 1.3T peak is as far as one would like to go on lams, and 1.7T peak for a C-Core that is a ratio of 1:1.3. So for a given number of turns on a core of equal dimension the C-Core could sustain a 30% higher voltage across that winding.

That is an increase in power of 70% for a given level of core distortion.

Or translated into the realm of mains power transformers it explains why strip wound cores, especially toroidal transformers are so small for their power rating. Of course increasing the cross sectional area of a stack of lams can equalise the power rating but that brings about an increase in winding length and hence an increase in leakage inductance and capacitance.

In the Audio Note™ high quality output transformers we use 50% or 55% nickel iron alloys, both oriented and non-oriented through a carefully developed, customised and proprietary heat treatment processes depending upon the application. These materials offer greatly reduced distortion at low signal levels, due to the very narrow hysteresis loop of these materials. The downside is their expense and lower saturation flux density, which in single-ended low power amplifier applications is not an issue. A small word about winding technology.

Traditionally, transformer design has focused on achieving the widest possible frequency response and this has been the main tenet of design priority for the past 80 or so years, in our research into the behaviour and interaction between coil and core we have discovered that when dealing with the highly permeable nickel cores, purely looking at frequency as the main arbiter of transformer quality is woefully inadequate and as a result we have spent years developing and refining the best way of winding the coil with special focus on improving the low level linearity and bandwidth, the end results speak for themselves.

From a purely practical standpoint, thin materials in the 0.1mm range are impossible to handle as large laminations, especially in the very mechanically soft nickel irons, and the C-Core format allows their use. Very thin laminations or strips are more important to very high permeability materials because eddy currents in thicker material, greatly reduces the effective permeability.

But remember that flux density is inversely proportional to frequency so at 1kHz the flux density in an output transformer will only be 2% of that at 20Hz, and 0.1% of it at 20kHz. Assuming 1.3T peak at 20Hz (for lams of M6) that gives 26mT peak at 1kHz and 1.3mT peak at 20kHz.

A high frequency power transformer such as used in a switch mode supply transformer would run the core at maybe 0.5T or more peak at 20kHz and then losses would become very significant. This is where ferrites with their very high intrinsic resistance become important, but useless for wideband audio applications.

Cobalt irons offer high saturation flux densities but they have a very wide hysteresis loop, not far from a semi-hard material and they don’t lend themselves to audio output transformer work where low level resolution is paramount.

This fact does not relegate cobalt based materials from other audio applications, for example permendur (49% cobalt) has uses in pole pieces for magnets in phono cartridges, loudspeakers and for electromagnets as the high saturation flux density allows for a greater density in the gap.

Here the material is generally driven into saturation by a DC polarising field.

Andy Grove & Peter Qvortrup, October 2003