Single Ended vs. Push Pull (Continued):
The Deep, Dark Secrets of Output Transformers

by Eddie Vaughn

A Burning Question

Here's a question I've been asked by several folks, including a gentleman who has a hearing condition that makes tizzy, grainy systems and loud listening levels painful. "Does the Carina SE EL84 amplifier have good detail and dynamics at low listening volumes, or must it be cranked up so that you can hear everything clearly?" I explained that it sounds very detailed and articulate at sub-watt output levels, and as a matter of fact it's inside the first watt where it truly excels. I immediately followed my statement with a question, "What amplifier are you using now?" It turns out that this particular gentleman has a push pull amp. Ah-ha, just as I'd suspected! While his PP amplifier is different (I'd say better) from most in that it operates it's four 6BM8s in strapped-triode and uses very minimal negative feedback, it still suffers from one of the drawbacks inherit to PP. He says that while it sounds positively wonderful at higher levels, he finds that it lacks detail and dynamics when played at very low volume. His main reservation about buying a Carina was the fear that it will exhibit this same trait.

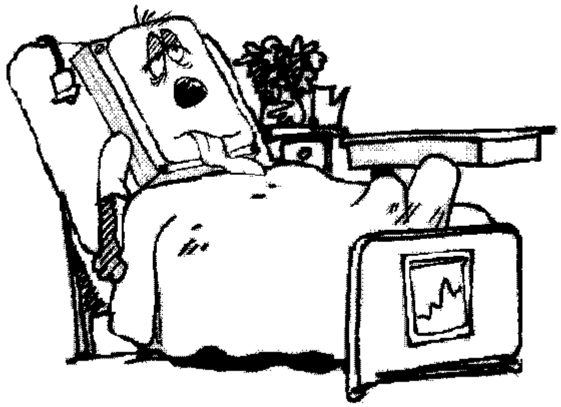
It won't. *Definitely* not.

This is a conundrum that confounds the "spec fanatics." Despite having much poorer distortion specs on paper compared to a push pull amplifier using feedback, a zero feedback SET usually produces better detail, *especially* at low volumes. Some of this lies within the amplifier itself, due to the fact that single ended amps usually have a lower signal path component count and hence less signal degradation, and less power supply intermodulations and such to due the fact there are usually less power supply stages. But to find the REAL reason why, you must go beyond the amplifier section and power supply, and look at.......the output transformer. The SET's output transformer (OPT) also confounds the spec fanatics, because at first glance to the untrained eye it shouldn't work well at all, because of it's air gap. The air gap is a "band-aid fix" that allows it to function with some degree of practicality. Because it reduces the inductive coupling efficiency, one would therefore think it would also only accurately convey the "macro" parts of the sound, and lose a lot of the fine details.

Again, it won't. *Definitely* not.

Neither the low volume fine-detail resolution of SET amplifiers, nor the seemingly inherit inability of PP amplifiers to properly render fine details and microdynamics at low volume are any kinds of secrets. Anyone who has owned both PP and SET amplifiers has observed it. Yet all too often, it gets blamed on the amp being PP. While this does have somewhat to do with it, it has a lot more to do with the *output transformer* than the amplifier itself, as this article on PP OPTs and transformer lamination materials will attempt to explain. We'll address the output transformer differences between PP and SE here, then we'll work towards the front end of the PP amp in consecutive articles. (WARNING: COPIOUS AMOUNTS OF WIGGY-HEADED, MIND NUMBING TECHNO-BABBLE AHEAD)

PP Core Saturation, or "Bass Iindigestion"



I knew I shouldn't have ate that 30 Hz bass note........

No transformer lamination material can achieve a theoretically infinite magnetic flux density. All "saturate" at a certain flux density. Flux density is achieved by applying a magnetomotive force, or *mmf*. The mmf in an OPT is *EMF* (electromotive force), more commonly known to us as *voltage*. Actually, mmf is the magnetic equivalent of electrical voltage! Here, it's the AC music signal from the power tubes that supplies the EMF, or voltage. The saturation point of a given OPT is mostly determined by the core dimensions and the lamination material used. The transformer's magnetic flux density increases proportionally with mmf, which increases proportionally with the applied EMF. Once the core reaches it's saturation flux density, any further increase in mmf does not (in fact, *cannot*) result in any further increase in magnetic flux density. An overloaded, saturated output transformer distorts the waveform in much the same way a saturated tube clips and distorts, creating harmonics in the secondary winding's output signal (NOT good!).

So as we can see, there is a limit to how much AC signal voltage a given OPT (whether PP or SE) can tolerate before core saturation rears it's head and everything falls off a cliff sonically. Actually, it's how much *total energy* is contained in each half-cycle, not just the voltage. A sinusoidal waveform of a given EMF (voltage/amplitude) increases in total energy as the frequency decreases. Why and how? The energy contained in a sinewave is proportional to the total area accumulated in the curve of that sinewave. Since each half-cycle of say, a 40 Hz waveform accumulates more area between it's ends (the zero line of the oscilloscope graph) than an 80 Hz waveform of equal amplitude (voltage) does, the flux density will attain higher values due to the higher mmf energy contained in the 40 Hz waveform. Therefore, the signal amplitude required to saturate a transformer decreases in a linear manner with a drop in frequency, and rises with an increase in frequency. In other words, if a transformer saturates at 20V RMS at 80 Hz, it'll saturate at around only 10V RMS at 40 Hz, and 40V RMS at 160 Hz.

Some transformer builders embellish their low frequency response specs by measuring them at very low signal levels, often only a few hundred milliwatts. In actual listening at substantial volumes, such an OPT will saturate rather easily at bass frequencies and distort. Quite often, an OPT nominally rated for 100 watts continuous RMS will distort at low bass frequencies at well under 25 watts. This problem also exists in power transformers. If a power transformer designed for 60 Hz line voltage is operated at 50 Hz instead, the flux density will reach a higher peak level on each AC half-cycle due to the greater energy contained in the 50 Hz sinewave, thus causing core saturation at a lower secondary current draw even if the voltage of each sinewave is the same.

On the flip side of the frequency band coin, it's nearly impossible to saturate any normal OPT with frequencies from the upper midrange audio band and up due to the low energy contained in the waveform. As a matter of fact, most OPTs have sufficient mutual inductive coupling to work *without a core* from about 2 kHz on up! The sound wouldn't be as coherent, but it *would* work without a core nevertheless.

SE Core Saturation and Air-Gapping

Now that we understand core saturation, let's hit on some basic PP OPT theory. In a PP amplifier's OPT, the power supply is connected to the center tap of the primary winding and a tube is connected to each end of the primary. This allows the tubes to conduct on alternate cycles of the AC input waveform, much like two persons in a boat with one rowing on each side. Since the DC bias currents to each tube flow in opposing directions in each half of the primary winding, they cancel each other out. Remember integers from high school math? Positive 10 plus negative 10 equals zero! However, in a SE amplifier's OPT, the primary has only two connections instead of the PP OPT's three. One goes to the power supply, the other to the plate of the power tube (or tubes if PSE). Therefore, the DC bias current flows *in one direction only*, and the end result is that there is none of the cancellation effect we saw with the PP OPT.

Those who know something of the fundamentals of transformer operation might be thinking, "But aren't we talking about AC voltage here, not DC current? Transformers turn AC voltage to magnetic energy and then back to AC, don't they? They don't pass DC from primary to secondary." This is true, but in the case of the SE OPT, a magnetizing voltage is created by the DC bias current flowing through the primary winding's resistance according to Ohm's Law. To your SE OPT, this DC voltage looks like one half-cycle of 0 Hz AC, if such a thing could actually exist. Low frequency AC was bad enough, but 0 Hz (infinitely low frequency) is *really* bad news for our OPT!

This voltage creates higher mmf, added on top of the mmf resulting from the AC signal.The resulting additional "bias" or "offset" will push the alternating flux waveform closer to saturation on one half-cycle than the other, thereby lowering the amount of AC signal a given OPT can handle before saturation. This offset DC bias effect is more easily understood by looking at in electrical, rather than magnetic terms. Figure 1 is an oscilloscope screen with a symmetrical AC sine wave, which for our demonstration purposes here depicts the magnetic flux created in a PP OPT.

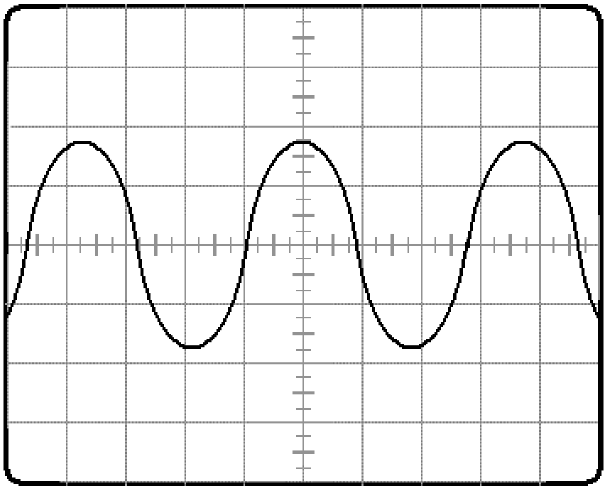


Fig 1 *Sine Wave with no DC offset*

We can see that both the positive and negative half-cycles are of equal amplitude, just as the magnetization in a PP OPT is equal in both directions. But what happens in a SE OPT, where offset DC is present? Figure 2 depicts our sine wave with an offset DC bias added.

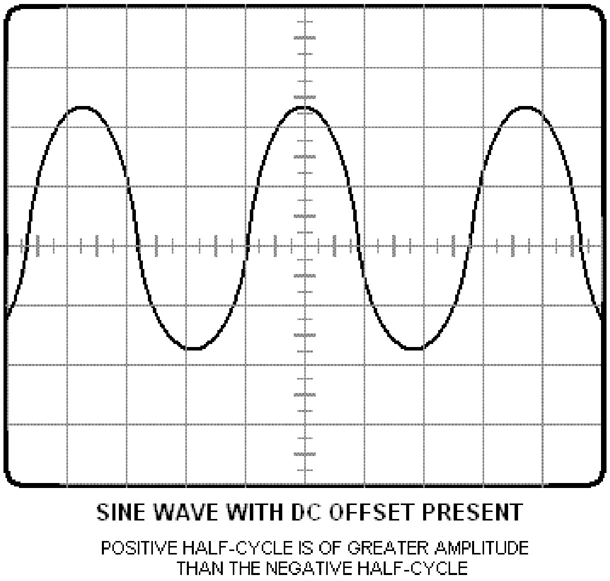


Fig 2 *Sine Wave with positive DC offset*

Notice that it is of greater amplitude on the positive half-cycle, which means that magnetic "headroom" before saturation is decreased in that direction in our SE OPT. Offset DC bias is bad news, to say the least. If you could operate your OPTs at extremely low cryogenic temperatures, the windings would become superconductive and you wouldn't have to worry as much about this condition. But, I for one prefer my listening room at around 72° F. :-) The inescapable reality is that the higher the DC current is in our SE OPT, the closer and closer the core is pushed to it's saturation point flux density.

Therefore you must do something, *anything* to raise the saturation point. Solution: A SE OPT has a shim in it's core between the stacks of E and I shaped laminations, to hold an air gap between them and reduce the inductance by breaking the magnetic "circuit". This helps to stave off early core saturation resulting from the offset DC. But, it also lowers the efficiency, limits bandwidth, and increases distortion and leakage inductance (more on that in a minute). When it comes to output transformers, you can't have your cake and eat it too!

We *could* just forego the air gap and make a bigger transformer, which spreads the mmf out over a larger core area, so that any given cross-sectional area of the core has a lower flux density than with a smaller core. But, this exacts a price in other areas as well. It increases stray magnetic fields in the core (fields not involved in the actual mutual inductive coupling), known as "leakage inductance." This leakage inductance "appears" to be in series with both the primary and secondary windings, so it manifests as a series impedance, reducing the signal level delivered to the speaker. Inductive reactance increases with frequency, so the effect is increased with rising frequency. It therefore rolls off the highs, just as in a speaker crossover.

Eddy currents are another problem. They are random, circular currents (just like eddies in a body of water, hence the name) induced in the lamination materials by the magnetic flux, that cause magnetic "ripples" in the flux field. Eddy currents are a major reason why transformers (and also electric motors) are built with stacked laminations and not solid blocks of metal for cores. The laminations are heat-treated to form a non-conductive oxide film on their faces, which electrically isolates each lamination from the next and prevents the conduction of the eddy currents throughout the core. This also helps to break up the eddy currents by limiting their physical size. The thinner each lamination is, the smaller the area that an eddy current is restricted to. The effect of lamination thickness on eddy currents is demonstrated in Figure 3.

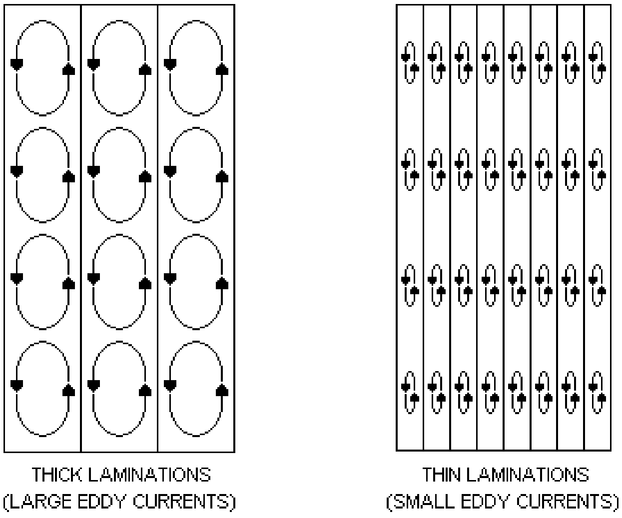


Fig 3 *Eddy currents and lamination thickness*

The eddy current effect increases with rising frequency, so the higher the desired maximum operating frequency, the thinner the laminations must be in order to minimize eddy currents and preserve high frequency coherency and bandwidth. A smaller core mass, thinner laminations, and high quality lamination materials all work to help reduce leakage inductance and eddy currents, and preserve high frequency coherency.

Another unwanted occurrence in inductive devices is "stray" or "parasitic" capacitance. This is capacitance from winding to winding or winding to core. The larger the core, the longer the distance around the circumference of the bobbin on which the wire is wound. The larger the bobbin circumference, the longer each turn of wire is, and the more winding area that exists to develop capacitance. This capacitance varies with signal voltage and frequency, and forms inductive-capacitive (L-C) resonances with the OPT's inductance. Needless to say, this wreaks havoc on our frequency response flatness. Not a happy thing. But, certain special winding topologies are used to reduce stray capacitance, and preserve the frequency response. Properly designed and wound, a good SE OPT can have a substantially large core mass before high frequency response suffers substantially.

The Hidden Glory of the SE OPT

Leakage inductance and stray capacitance are not the exclusive problems of SE OPTs however, they plague PP OPTs as well, and also inductors, power transformers, and autoformers. So if both PP and SE OPTs suffer from these same anomalies, then PP is superior because it doesn't need an air gapped core and is less susceptible to saturation, right?

Wrong. Although the SE OPT's offset DC is a drawback, it's also a blessing in that it keeps the core magnetized. The offset DC creates a static magnetic field that holds the transformer in a highly linear region of it's magnetization curve, even at very low signal levels. It avoids ever seeing a zero flux condition, whereas PP does not. In a PP OPT there is no offset DC, so with no signal present there is no mmf, and no magnetic flux. The PP OPT depends solely on the AC signal to provide the magnetizing or "excitation" current, while a SE OPT *stays magnetized 100% of the time*. It's very important to understand this, because it's a critical reason why SE amplifiers are more coherent and detailed at low volumes than PP! There is no hysteresis or core loss (more on that in the next section). Granted, this comes at a price, as the air gap and necessitated larger core mass do lower the efficiency and create more distortion and frequency response problems. But, it does knock hysteresis in the head.

I've read claims that the air gap is actually beneficial to the sound, and is what causes this phenomenon. This is 100% untrue! The air gap is detrimental in every way, and is a "necessary evil". it would be infinitely preferable to not have an air gap in a SE OPT if that were possible. In spite of escaping the need for an air gap, the PP OPT is faced with another, inescapable handicap in that the two halves of the AC cycle are of opposing polarity. This means the magnetic flux *is in a different direction on each half-cycle*. The PP OPT faces a grievous hurdle here, at the sinewave's zero signal crossover point where the effects of hysteresis take their toll on it.

Hysteresis, the Hysteria Inside Your PP OPT

Hysteresis is an unfortunate phenomena, and also an unavoidable one. Hysteresis is due to the existence of retentivity in the magnetic domains of the lamination material, the very thing that makes certain metals permanently magnetic in the first place. In simplest terms, retentivity can be thought of as residual magnetism, although it will be addressed more in depth later. Magnetic domains are regions of magnetic alignment in ferromagnetic materials, resulting from quantum mechanical interactions at the atomic level. A high degree of magnetization naturally occurs in ferromagnetic lamination materials within individual domains, but in the absence of an external mmf these domains are randomly oriented. An externally applied unidirectional mmf aligns the domains with the direction of the magnetization field it creates. The end result is a large net magnetic flux, a multiplication or amplification of the applied mmf.

Figure 4 depicts a hysteresis loop and it's parts. Examining it will help you to better understand the rest of this section, and how it applies to our OPT.

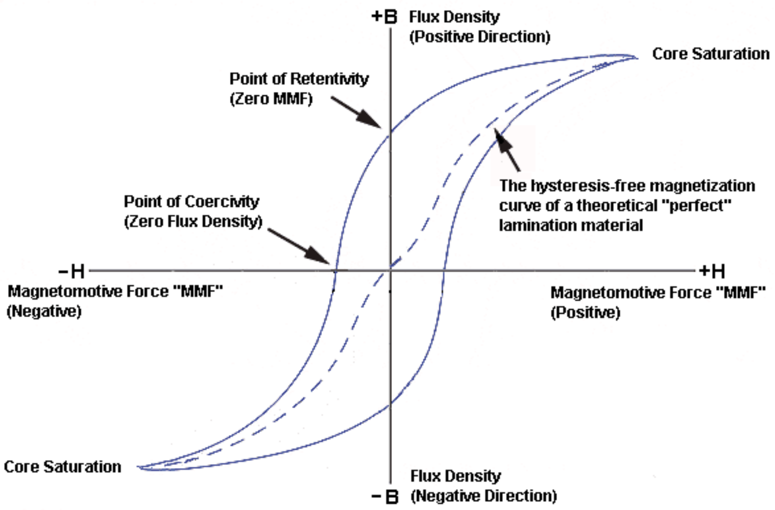


Fig 4 *A typical hysteresis loop, or "B-H loop"*

When the applied mmf in a transformer ceases (the zero voltage line of the AC sinewave), the magnetic flux should theoretically return to zero. However, because of retentivity (the tendency to retain residual magnetism) the flux does not fully relax back to zero when the mmf is removed, due to the fact that some of the domains will still retain their unidirectionally oriented alignment. Just as we read at the beginning that no transformer lamination material can achieve a theoretically infinite magnetic flux density, no ferromagnetic lamination material completely loses it's domain alignment when the mmf is removed, and returns to zero flux density. All exhibit a certain degree of retentivity. This retentivity makes possible the creation of permanent magnets, but in our PP OPT this is highly undesirable! The point at which the mmf ceases (the zero line on the oscilloscope graph) and flux due to only residual magnetism remains is called the *point of retentivity*. The level of residual flux at the point of retentivity is called the *remanence*. It requires considerable energy to overcome the remanence and drive the core to the point of true zero flux, called the *point of coercivity*. In our PP OPT the mmf expended to take the core from the point of retentivity to the point of coercivity is called the *coercive force* or *coercivity*. The coercive force can be considered wasted energy, and this inefficiency is called *core loss*. This is one reason why PP is less articulate, dynamic, and detailed at low levels than SE.

After full negative-direction magnetization has occurred, the cycle reverses again and begins it's positive magnetization swing. However, the point of coercivity is different on the return cycle, because it is skewed by what is now a different retentivity polarity. Because the magnetic polarity of the point of retentivity is opposite on each half-cycle, so is the point of coercivity. Because of this, the magnetization curve is not a uniform, linear line in both directions. This impossibility to precisely track a linear remagnetization curve when the alternating mmf is applied is the property called *hysteresis*. Hysteresis causes the magnetization curve to trace out an S shaped loop, which is where the *hysteresis loop* in Figure 4 gets it's name. The left-to-right width of the hysteresis loop at the center point or *waist* is the degree of hysteresis present. It is also sometimes called the *B-H loop*, where B is the flux density and H is the magnetomotive force, or mmf. All ferromagnetic materials exhibit a certain degree of hysteresis, as the relationship between B and H is never perfectly linear. The hysteresis loop can be simply thought of as a representation of the magnetic flux density (B) as a function of the mmf (H). The more magnetically linear the material is, the narrower the waist of the hysteresis loop.

Lamination Materials and Their Properties

OPTs demand lamination materials with high magnetic *permeability* (the ease with which it is magnetized) and low retentivity and coercivity. The higher the magnetic permeability, the lower the mmf that is required to attain a given flux density, and oftentimes a smaller core mass can be used as a result, along with it's benefits of lower leakage inductance and stray winding capacitance. If saturation becomes an issue, core size can be increased accordingly, and special winding techniques used to help overcome the increased stray capacitance that usually results from the use of larger core mass. The lower the retentivity of the lamination material, then usually less coercive force that is required to overcome it and remagnetize the steel in the opposite direction. So, the higher the magnetic permeability and the lower the retentivity, the better that details and microdynamics will be rendered at lower signal levels.

Such high quality lamination materials are very expensive. GOSS (grain oriented silicon steel) is one of the most commonly used lamination materials for transformers and electric motors, because of it's desirable magnetic properties. Grain orientation lowers core losses and extends the saturation point, and about 4 to 4½ percent silicon lowers the remanence (retentivity). GOSS laminations are annealed at about 1500° F (820° C) before use. Annealing relaxes the internal stresses caused by rolling out the sheet and then stamping the E and I shapes from it, and forms a non-conductive oxide film to reduce eddy currents. M6 is the grade of GOSS most often used in high quality power transformers and PP OPTs.

M19 is a non-oriented steel commonly used in filter inductors, low-end power transformers for tube amps, and in some SE OPTs. It has lower magnetic permeability than M6, and requires greater core mass per volt-amp of output in power transformers. It requires more energy for magnetization reversal, and has a wider, less linear hysteresis loop. Because of this, it is less efficient in power transformers than M6. Due to the fact that more of the AC sinewave's energy is wasted as heat in reversing the flux direction than with M6, power transformers built from M19 exhibit higher heat rise due to the higher core losses. Because of it's inferior properties, it should never be used in PP output transformers.

Some very high-end PP OPTs use exotic materials such as M4 GOSS, which has superior properties to M6 but is very expensive. Amorphous iron is another exotic material used in very high-end OPTs. It has an amorphous molecular structure similar to that found in glass. It has low retentivity/coercivity and high permeability, and is therefore extremely efficient, with a very narrow hysteresis loop. However, it saturates at a lower flux density than many materials, especially at low frequencies.

Nickel is added to iron to improve the permeability and lower the core losses. It's drawback is a far lower saturation point than GOSS. M6 typically saturates at around 20 kilogauss/2 Tesla, while iron with only 50% nickel content saturates at about 15 kilogauss/1.5 Tesla. Because of it's extremely low core loss, nickel iron is one of the finest materials available for transformers. 80% nickel iron was originally christened Permalloy back in 1914, when Gustav Elmen of Bell Laboratories discovered it's superb properties, but today these alloys may contain different nickel contents. The premium transformer grade Permalloy consists of 79% nickel, 17% iron, and 4% molybdenum. It has the highest permeability and lowest core loss of any common transformer core material, which makes it a very sensitive and low distortion lamination material. It's low saturation flux density of 8 kilogauss/.8 Tesla and extremely high cost limits it to certain specialty applications, such as recording studio microphone transformers, step-up transformers for low output, moving coil phono cartridges, and other critical small signal applications. It is also used as record head cores in the finest tape recorders.

79% - 80% nickel Permalloy is also known by the names Supermalloy, Mu-Metal, Ultraperm, and it's AISI/SAE classification, M-1040. 36% nickel Permalloy is commonly known as Radiometal, and 48% to 50% nickel is called SuperRadiometal. Permeability falls as the nickel content falls, and the saturation flux density point rises. 80% nickel Permalloy has a saturation flux density of only .75 Tesla, 79% nickel saturates at .8 Tesla, 50% nickel saturates at 1.5 Tesla, and 48% nickel SuperRadiometal has a saturation flux density of 1.6 Tesla. So, the transformer engineer must carefully consider his application and choose the appropriate nickel content to avoid core saturation. Nickel iron laminations must be correctly annealed to ensure the best magnetic properties, and care must be taken to not expose them to high impact after annealing. Hard, high-G impacts (such as dropping a completed transformer on a hard floor) can change the magnetic properties of nickel iron, especially high-nickel content alloys.

High-cobalt steels such are sometimes used in certain specialty applications. They can attain very high flux densities before saturating, higher than even M4 or M6, but have higher retentivity and therefore higher core losses. Were it not for their extremely high cost, cobalt alloy steels would be very useful for power supply filter inductors. Size for size, a cobalt steel inductor is capable of handling much higher DC currents before saturation than the commonly used M19 or M6 materials.

Because SE OPTs largely avoid the hysteresis effect from maintaining magnetization in a linear region, their construction permits lamination materials that could never be used in PP OPTs, such as M19. However, most high quality SE OPTs are made of M6 nonetheless. Because SE OPTs suffer less from core losses than PP OPTs, cobalt steels are sometimes used in certain SE OPT applications.

Torodial Output Transformers

Although toroidal power transformers are very common, toroidal audio transformers are not seen much, due to their inherit problem of high intolerance to offset DC. They will saturate very quickly because their flux density level typically is already higher than that of an E-I lamination transformer, and there is no air gap in their core. However, a few companies have "worked out the bugs" somewhat with winding topologies and core geometries that they are very secretive about. Despite their lower tolerance to offset DC bias, toroidal OPTs enjoy several specific advantages over E-I OPTs.

Toroidal transformer cores are made by winding a continuous strip of the core material into a donut shape, called a *toroid*. Because of the way the core is made, 100% of the grain is oriented in the same magnetic direction. This eliminates one of the major disadvantages of E-I lamination transformers, in which only about 60% of the grain is oriented in the same magnetic direction. Although the grain of a stamped-out lamination is oriented in one direction only, the magnetic flux in an E-I transformer runs in all directions, and is asymmetrical in different directions as well, as shown in Figure 5.

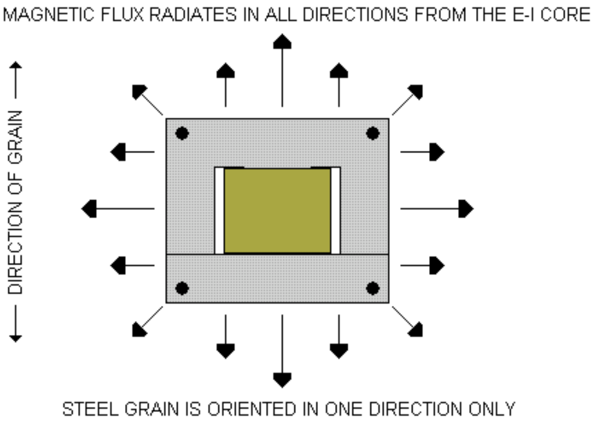


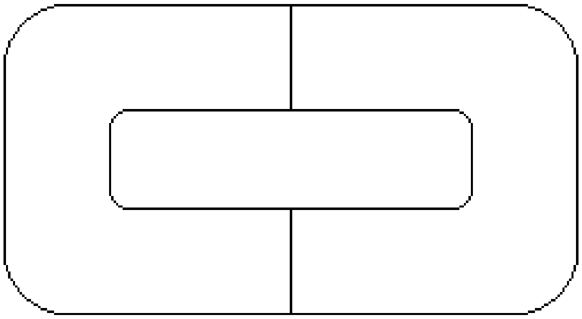
Fig 5 *Grain orientation direction versus magnetic flux direction in an E-I core*

The E-I core's magnetic flux is omnidirectional, but the lamination steel's grain is unidirectional, so much of the core is "out of sync" with the flux direction. In a toroidal transformer, the flux is symmetrical about the core, in one direction only. In other words, any given cross-section of an E-I transformer sees a different flux direction and density, where any given cross-section of a toroidal transformer sees the same flux direction and density. This gives toroidals very low leakage inductance.

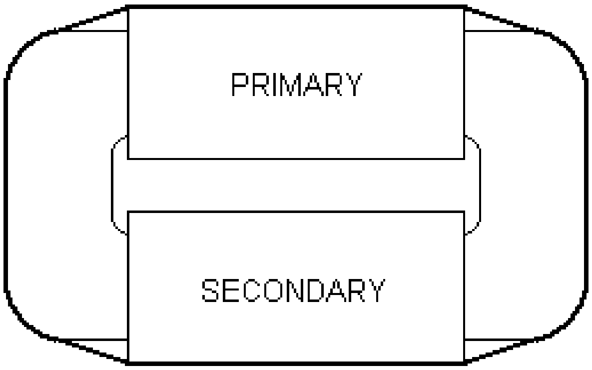
The windings are then evenly wound directly on the symmetrical, gapless, round toroidal core, without a bobbin. Because the windings are symmetrical and even, the inter-winding capacitance can be very high unless special winding techniques are employed to reduce it. However, because the toroidal's windings and flux field are symmetrical, several advantages are realized. The flux density is much higher than in an E-I lamination transformer, and every turn of wire sees the same flux density. As a result, the level of mmf necessary to establish and maintain the minimum flux density required for coherent, full bandwidth mutual inductive coupling is very low. This minimal mmf, called the "quiescient" or "excitation" power, is typically over a dozen times lower for toroidals than E-I transformers. Not only are toroidal OPTs very efficient (typically over 95%) , they are ideal for push pull applications where little or no offset DC is present to cause core saturation. The toroidal OPT's low hysteresis and excitation mmf makes for much better detail and dynamic response at low volumes.

C-Core Output Transformers

C-cores are made in a manner similar to toroid cores, by winding a strip of material, usually M6, into a shape as shown below in Figure 5. It is bonded together and annealed just like a toroid core, but is then cut into two identical C shaped halves. The cut faces are precision ground exactly square and parallel, as it is of the utmost importance that they fit together perfectly, or a large loss of efficiency will result. The wound bobbins are placed over the legs of one core half, and the other core half inserted into the bobbin until their faces seat together. For SE operation, an air gap shim is added before assembly. Then, the core is banded tightly around it's circumference with a steel strap to ensure tight contact of the core halves.



CORE HALVES FITTED TOGETHER, WITHOUT BOBBINS INSTALLED



ASSEMBLED C-CORE OPT

Fig 6 *C-core transformer construction*

Like toroidal OPTs, C-core OPTs are not highly common in today's tube audio world. However, like toroids, they do exhibit certain advantages over the much more common E-I lamination transformer. They are more efficient than E-I transformers, though not as efficient as toroidal designs. The bobbins can be wound on conventional equipment, unlike toroidal transformers. Because the primary and secondary are wound on separate bobbins and reside on different legs of the C-core, they are physically separated from one another and their inter-winding capacitance is practically nonexistant. The main disadvantage of the C-core topology is that it's leakage inductance is quite high.

To Parafeed or Not To Parafeed, *That* is the Question

Parafeed (parallel feed) is worth mentioning here in closing, while we're on the topic of OPTs. In a parafeed topology, the power tube is loaded by an inductor, resistor, or active constant current source, and a DC blocking capacitor couples it to the OPT. It has became very trendy due to several reasons. It has far better immunity to power supply ripple and noise (higher PSRR, or Power Supply Rejection Ratio), because the power supply is not routed through the OPT as in conventional SE output stages. The output stage's AC ground is the OPT primary directly to ground versus back through the power supply, which nets a lower impedance. There is no offset DC present in the OPT, because it is blocked by the "parafeed capacitor". In the absence of DC bias current, the OPT can be made much smaller, and without the air gap required by conventional SE OPTs. Due to the small core mass, leakage inductance and stray capacitance are very low. Manufacturers of parafeed amplifiers tout the parafeed topology as the be all, end all of output topologies, with the best specs and best sound. However, they do not tell you the whole story.....

It's worth noting here that although they are single ended, *parafeed OPTs suffer from hysteresis in the same manner as PP OPTs do*. This is of course due to the fact that no offset DC is present to hold a linear static magnetization. But, a high permeability, low core loss material such as Permalloy can be used to great effect in the parafeed OPT to minimize hysteresis effects. However, there is no way to avoid the other problems inherit to the parafeed topology cause by the DC blocking capacitor, such as frequency-dependent phase shifts, a charge/discharge curve that is non-linear with frequency, and losses caused by the capacitance being in series with the OPT's inductance. Although parafeed can sound incredible if done correctly, nothing is perfect. Especially transformers ...

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