# Composite Cores Offer the Best of all Worlds

By
George Orenchak
TSC Ferrite International
39105 North Magnetics Boulevard
Wadsworth, IL 60083

## Abstract

The inherent high resistivity of "soft ferrite cores" minimizes eddy current losses and the inherent distributed air gaps of "iron powder cores" minimize winding losses. The two can be married as a composite core in order to exploit each materials inherent advantage while minimizing each materials short falls. Such a composite core offers a cost effective solution ideally suited for switching regulator inductors, flyback transformers and power factor correction (PFC) inductors.

## Introduction

The selection of magnetic core materials for a particular inductor or flyback transformer application can be very confusing. Each magnetic material has inherent advantages and disadvantages. Attributes such as permeability, core loss, saturation flux density, winding losses caused by fringing flux, electromagnetic emissions and costs all need to be considered. The objective often is to choose a core material that will result in a design with the lowest cost component, that supplies enough inductance to filter high frequencies or store energy, functions with an acceptable temperature rise and does not emit electromagnetic interference. Marrying inexpensive soft ferrites that have low core loss with inexpensive iron powder that have distributed air gaps in a composite core is a great way to meet such objectives.

Since EE or EI shaped cores are most cost effective due to their simplicity and the fact that the windings can be wound on bobbins with multiple head high speed automated equipment this paper will consider them to be the core shape of choice.

## Material Characteristics

Soft ferrites are relatively inexpensive, have high permeability and inherently have high electrical resistivity, which results in low core loss at high frequencies, but soft ferrites saturate with minimal magnetizing force if they are ungapped. Gapping a soft ferrite core helps to prevent the core from saturating because the gap causes the hysteresis loop to shear over and therefore much more magnetizing force is required to saturate it. Figure #1 shows the BH Loops of a soft ferrite ungapped and gapped. Magnetic flux fringes around large centralized gaps in a cores magnetic flux path. Figure #2 shows that if the gap is located near the winding as in an EE core the fringing flux intersects the winding and creates excessive eddy currents in the wire, which cause high winding losses. The result is a high temperature rise and a hotspot in the transformer. Figure #3 shows that if the gap is located away from the winding as in an EI the fringing flux does not intersect the windings but instead strays and escapes as electromagnetic emissions. Due to assembling costs it is not practical to distribute the gap of a soft ferrite core by assembling numerous pieces of soft ferrite together to make a soft ferrite with a distributed gap. Soft ferrite manufactures have attempted to make distributed gapped soft ferrite cores but have not been able to achieve loadings of sintered soft ferrite powder into a plastic or resin carrier that result in effective permeability's greater than ~20, which in most cases is to low to be useful.

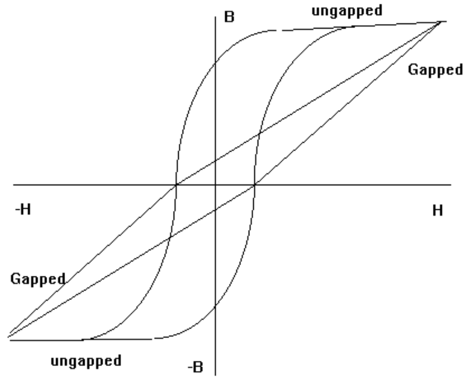



Figure #1

**Figure #2**
**Gapped Ferrite EE core**

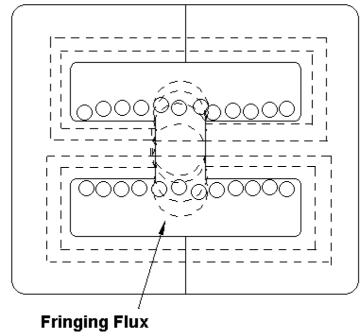



Figure #2

**Figure #3**
**Gapped Ferrite EI core**

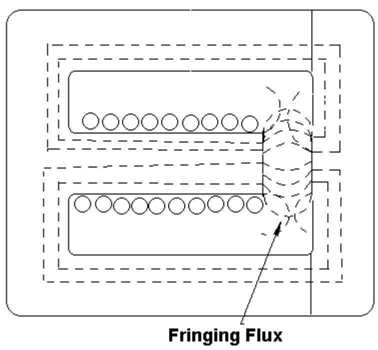



Figure #3

**Figure #4**
**Iron Powder EE core**

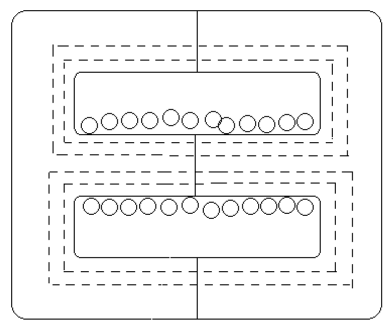


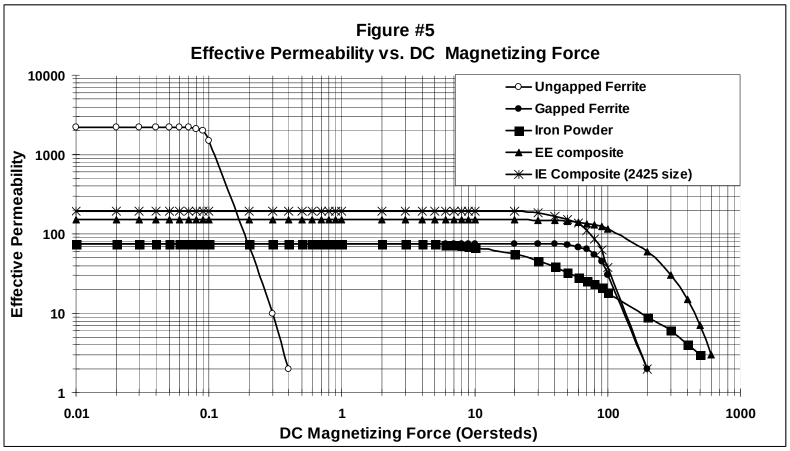
Figure #4

Iron powder cores inherently have small-distributed air gaps throughout their magnetic flux paths. The gaps are very small so the fringing flux is minimal. The flux does not intersect windings nor does it escape as electromagnetic emissions as figure # 4 exhibits. Iron powder cores are very inexpensive however they have relatively high ac core losses.

The tradeoffs between iron powders with inherent distributed gaps but high core loss and soft ferrite with low core loss but the need for large centralized air gaps that cause fringing flux problems are apparent but the choice of marrying the two materials together to take advantage of their strengths while minimizing their short comings is often overlooked.

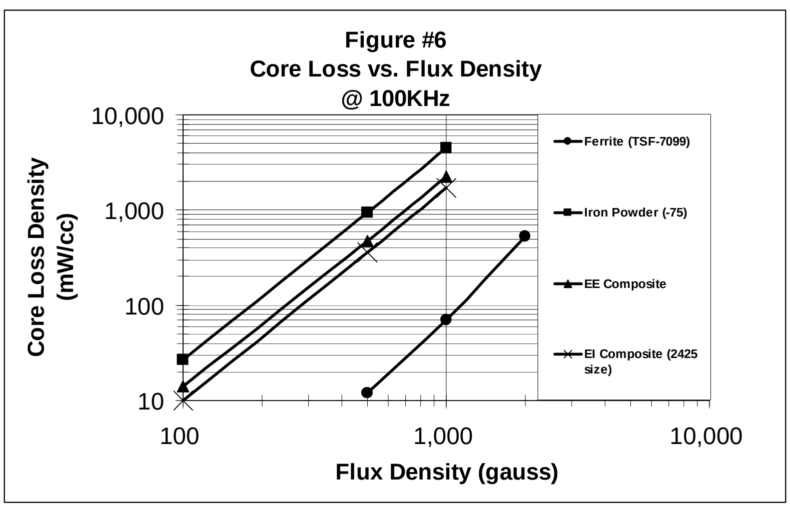
## Effective Permeability & DC Bias Magnetizing Force

Figure #5 compares the effective permeability vs. dc magnetizing force of ungapped soft ferrite, iron powder, soft ferrite gapped to the same effective permeability as the iron powder, an EE soft ferrite / iron powder composite core & an EI 2425 composite core made of a soft ferrite (E core) mated with an iron powder (I bar). The inductance of the ungapped soft ferrite core set rolls off with minimal dc current applied because it saturates quickly. The iron powder has lower effective permeability but the effective permeability does not start to roll off until 10 oersteds of dc magnetizing force are applied. The iron powder saturates slowly resulting in a soft swinging inductance versus dc bias curve. This is advantageous since it will continue to provide some inductance in overload conditions rather than abruptly saturate. The soft ferrite gapped to the same effective permeability as the iron powder supports a lot of dc magnetizing force but it saturates abruptly and the fringing flux is problematic. The composite EE core has a higher effective permeability than the straight iron powder so the turn count or the core size can be reduced, and the roll off is minimal to nearly 100 dc oersteds. The composite EI core has even higher effective permeability but it does start to slowly roll-off after at approximately 30 dc oersteds. The soft ferrite / iron powder composite core is a great choice for applications requiring dc bias because it has higher effective permeability, is slow to saturate and does not have the fringing flux problems.




## Core Loss

Figure #6 compares the core loss density of soft ferrite, iron powder, an EE soft ferrite / iron powder composite core & an EI 2425 composite core made of a soft ferrite (E core) mated with an iron powder (I bar). The core loss density of the soft ferrite is insignificant compared to the core loss density of the iron powder. When one half of the magnetic path length of an iron powder core set is replaced with soft ferrite the component core loss density is reduced by ~50%. Even larger core loss density reductions can be achieved by replacing more of the iron powder with the lower core loss soft ferrite as the EI composite shows (core loss reduction of ~62%).




## Standard Composite E Cores

Table #1 shows a list of standard soft ferrite / iron powder composite E core sets that are available and their associated inductance index ($A_L$ value). Custom sizes could also be tooled for a minimal tooling charge.

**Table #1**

| Industry Core Size Designation | TSC Part Number | Inductance Index $A_L$ (nH/$N^2$) | Magnetic Path Length $L_e$ (cm) | Effective Core Area $A_e$ ($cm^2$) | Effective Core Volume $V_e$ ($cm^3$) | Window Area $W_a$ ($cm^2$) |
|---|---|---|---|---|---|---|
| EF12.6 | CMP1-13-06-04 | 75 | 2.959 | 0.130 | 0.386 | 0.250 |
| EF16 | CMP1-16-08-05 | 100 | 3.761 | 0.199 | 0.750 | 0.398 |
| EE187 | CMP1-19-08-05 | 110 | 3.977 | 0.225 | 0.894 | 0.545 |
| EF20 | CMP1-20-10-06 | 120 | 4.614 | 0.315 | 1.454 | 0.525 |
| EE2425 | CMP1-25-10-06 | 160 | 4.899 | 0.394 | 1.928 | 0.850 |
| EE30 | CMP1-30-15-07 | 155 | 6.607 | 0.573 | 3.785 | 1.344 |
| EE375 | CMP1-34-14-09 | 230 | 6.942 | 0.813 | 5.646 | 1.634 |
| EE21 | CMP1-41-16-12 | 370 | 7.750 | 1.487 | 11.521 | 1.754 |
| EE4215 | CMP1-43-21-15 | 335 | 9.834 | 1.838 | 18.075 | 2.888 |
| EE4220 | CMP1-43-21-20 | 405 | 9.834 | 2.334 | 22.951 | 2.888 |

## Summary

Composite soft ferrite / iron powder EE cores offer a cost effective solution for applications such as switching regulator inductors, flyback transformers and power factor correction (PFC) inductors where a gapped magnetic core is needed. The soft ferrite / iron powder composite core minimizes fringing flux because it has a distributed air gap. It has half the core loss of a straight iron powder core set and the effective permeability and associated inductance indexes (AL values) are higher which results in lower turn counts or smaller core sizes. A large selection of standard sizes are available and both materials are relatively inexpensive.

## Acknowledgements

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## References

Snelling, E.C., Soft Ferrites Properties and Applications, 2nd edition, Butterworth, 1988

"Soft Ferrites A User's Guide" Magnetic Materials Producers Association, MMPA SFG-98, 1998.

McLyman, Wm. T., Magnetic Core Selection for Transformers and Inductors, Marcel Dekker, New York, NY.