Equivalent Ferrite Materials, what cross-reference list does not tell you

Marcos Luna

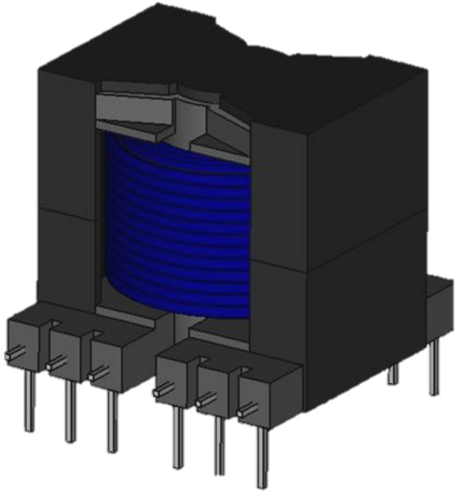
Timeline

- **Introduction - Are equivalent materials really equivalent?**
- **Analysis and hardware verification of equivalent low-frequency ferrite material**
- **Analysis of equivalent high-frequency ferrite material**
- **Conclusions**

Introduction

Introduction

To design a magnetic, the choice of material is one of the most important parts. Different suppliers offer a wide catalogue to choose the best option depending on the application.



Sometimes, engineers make magnetic designs with a certain material, but for different reasons (economical, logistical…) they end up using "equivalent" materials from other manufacturers.

- MANUFACTURER 1
  [Material A]
- MANUFACTURER 2
  [Material B]
- MANUFACTURER X
  [Material X]

Are they equivalent?

Introduction

CROSS-REFERENCE

There are many cross-reference tables with ferrite materials for different manufactures.

- Permeability
- Saturation
- Power Losses
- …

Specifications for magnetic materials are collected from the datasheet of each manufacturer.

To carry out the investigation, 5 alternative materials have been chosen for low-frequency and high-frequency power conversion application.

The information that manufacturers give us is often very inaccurate, based on charts where the values must be extracted. This makes it difficult to characterize the materials.

Low-Frequency Ferrite

Low-Frequency Ferrite

MANUFACTURER SPECIFICATIONS

This material is very common in the design of power transformers in converters up to 400 kHz. It offers a flat loss in a wide range of temperatures (20ºC to 100ºC) compared to other materials and it could be available in many different core shapes.

The five materials previously chosen are compared against each other based on the datasheets provided by the manufacturers themselves.

MANUFACTURER A

MANUFACTURER B

MANUFACTURER C

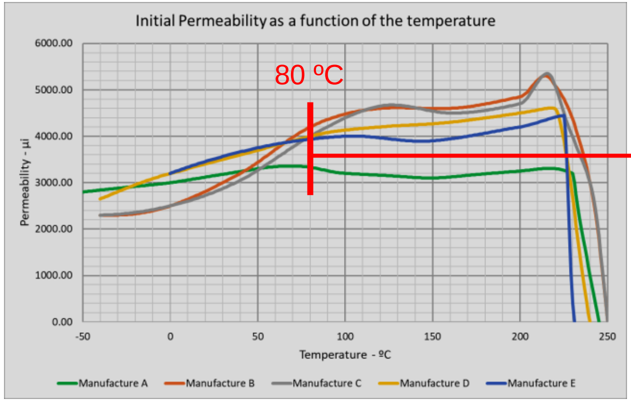
MANUFACTURER D

MANUFACTURER E

Low-Frequency Ferrite

INITIAL PERMEABILITY AND SATURATION FLUX DENSITY

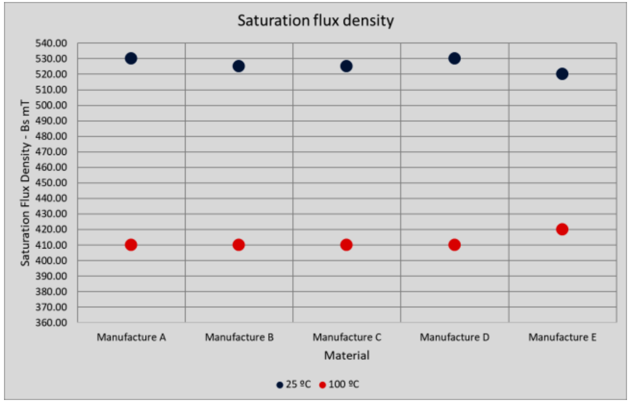
One of the first parameters that engineers check is the initial permeability of the materials, which determines the minimum number of turns needed to comply with the inductance requirement.



MANUF.	PERM
A	3335
B	4200
C	4000
D	4000
E	3937

Manufacturer A material exhibits the most linear behavior for the entire temperature range. Materials from other manufacturers have more similar trends.

Saturation flux density labels the maximum peak of magnetic field allowed so that the component does not reach saturation.



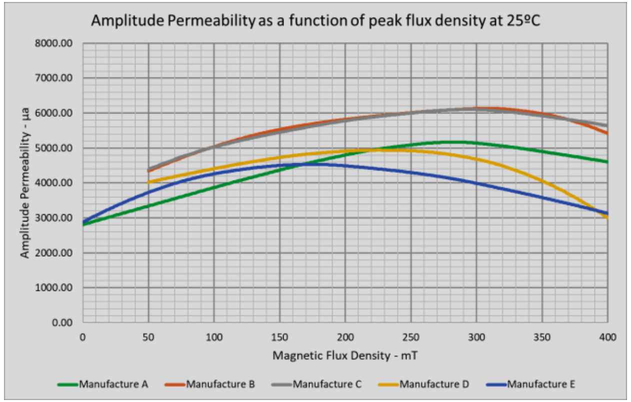
There are minor differences between all of the materials. Neither is better or not than the rest.

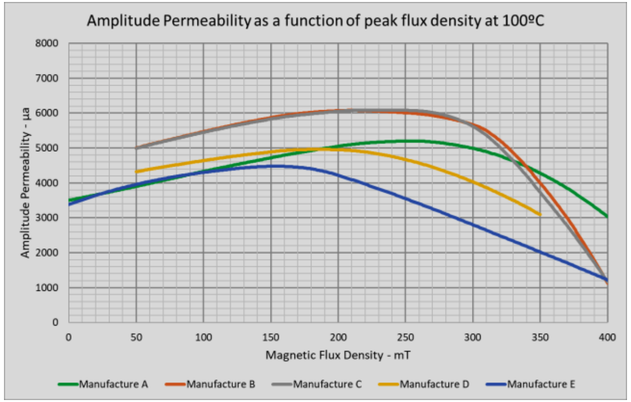
Low-Frequency Ferrite

AMPLITUDE PERMEABILITY VS MAGNETIC FLUX DENSITY

Another important parameter is the amplitude permeability, which means that the changing in the permeability depends on the peak flux density.

Amplitude permeability is also affected by the temperature of the magnetic component.





At 25ºC, the materials A, D and E exhibit a close variation, such as B and C, that have almost the same trace.

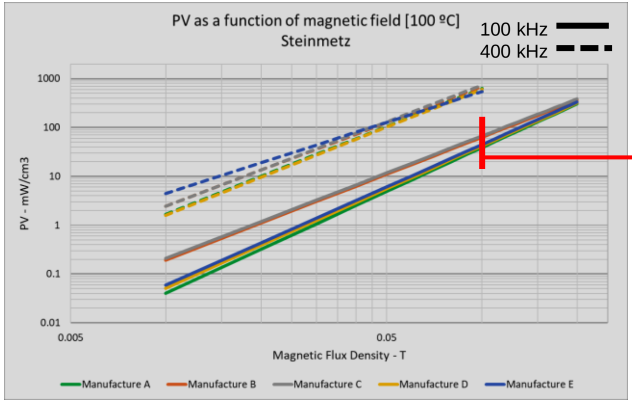
At 100 ºC, differences among the materials begin to be more evident.

Low-Frequency Ferrite

POWER LOSSES

To compare the power loss of the materials , the classical Steinmetz's equation has been used [1], calculating the coefficients based on the information provided by the ferrite manufacturers.

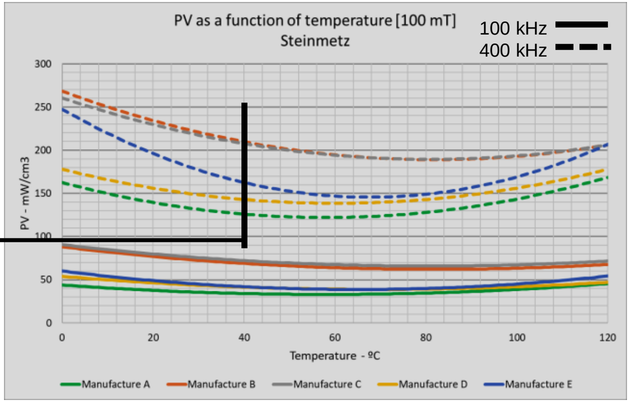
This information is in different charts that show the variation of the power losses vs. frequency, magnetic flux density and temperature.



PQ40/40 calculated losses based on manufacturer data

MANUF.	LOSS
A	0.79 W
B	1.29 W
C	1.38 W
D	0.86 W
E	0.92 W

MANUF.	LOSS
A	2.58 W
B	4.30 W
C	4.25 W
D	2.93 W
E	3.33 W



Again, three materials (A, D, E) showed similar performance around 100 kHz and started to differ as the frequency increases.

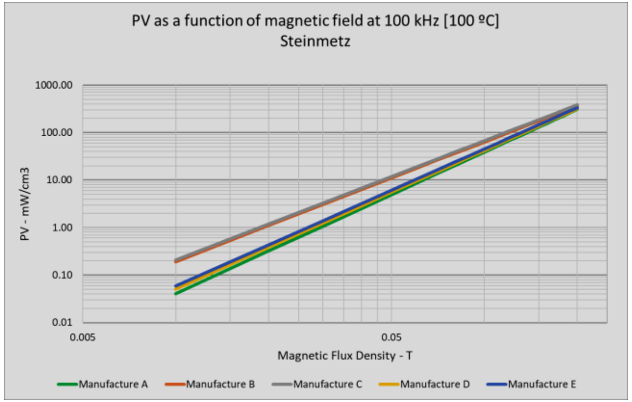
With lower core losses and a less temperature dependency, A and D exhibit the best performance.

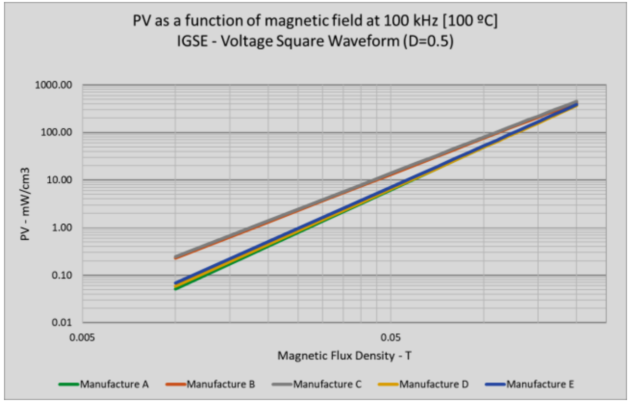
Low-Frequency Ferrite

STEINMETZ VS IGSE

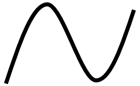
The specific power loss information provided by the manufacturers are based on measurements carried out with a sine wave and toroid,

An improved generalized Steinmetz's equation (IGSE) [2] has been proposed and compared with the classical Steinmetz's equation.

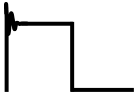




STEINMETZ

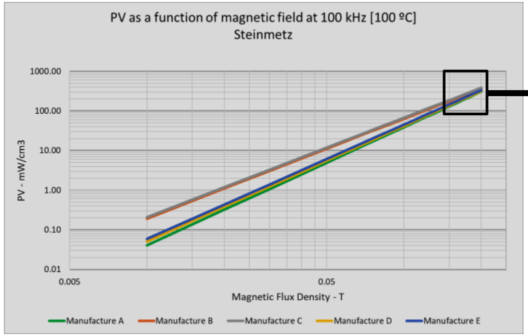


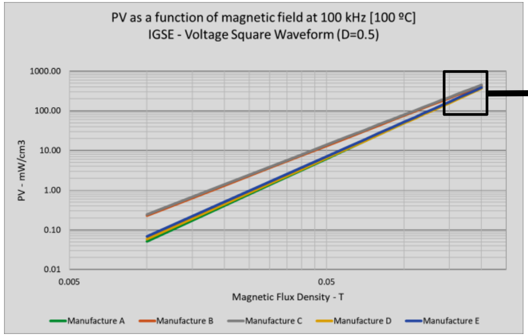
IGSE

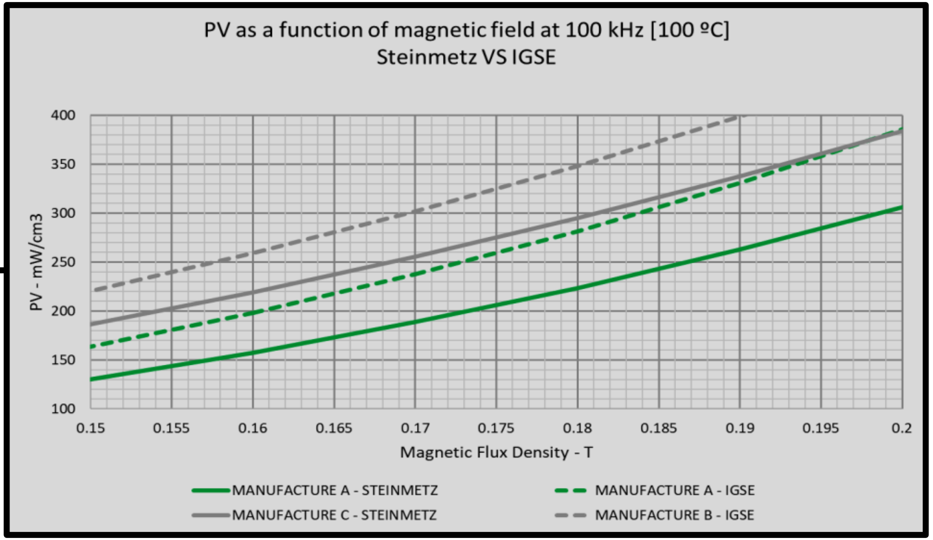


Low-Frequency Ferrite

STEINMETZ VS IGSE







A zoomed-in view in the range of 0.15 – 0.2 T has been done to emphasize the differences between the materials. As it can be seen, IGSE shows higher losses for the same magnetic flux density, because it takes into account the different fluctuations of the signals applied to the magnetic.

Low-Frequency Ferrite

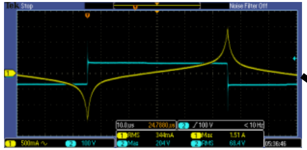
EXPERIMENTAL TEST

Three hardware tests have been carried out to evaluate the information provided by the manufacturers. For the sake of simplicity, two materials have been selected.

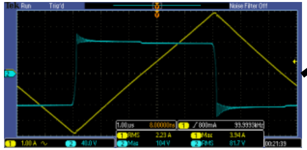
These materials are compared between them with the extracted information of the datasheet and the results for each test.

Manufacturer A **VS** Manufacturer C

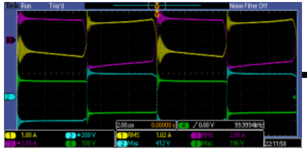
- **SATURATION TEST**

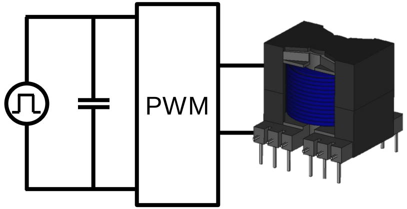


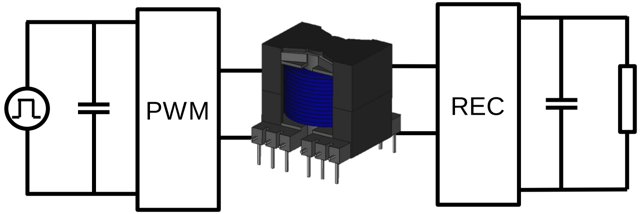
- **CORE LOSS TEST**



- **CONVERTER TEST**







Low-Frequency Ferrite

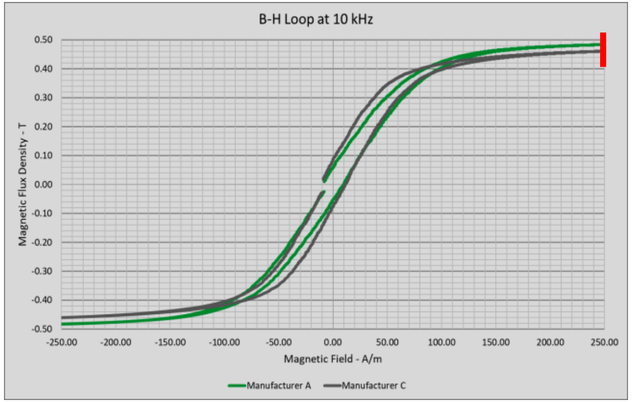
SATURATION TEST

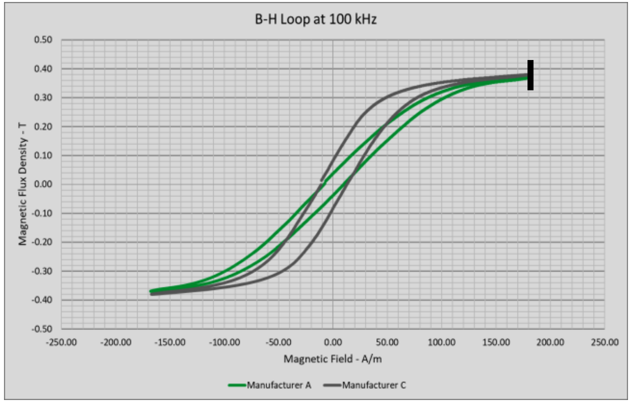
The following results have been obtained at the given frequencies of 10 kHz and 100 kHz.

At 10 kHz, saturation difference between A and C manufacturers is 0.02 Tesla, and there is a difference of 0.05 and 0.06 Tesla with respect to the datasheet information.

At 100 kHz, manufacturer A and C exhibit a decrease of more than 0.1 T in the saturation, which is quite significant.

These values are not provided in the manufacturers datasheet.



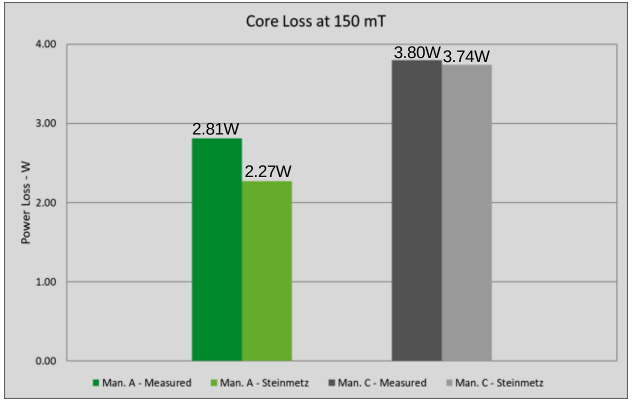


MANUF.	Datasheet 10 kHz	Measured 10 kHz	Measured 100 kHz
A	0.53 T	0.48 T	**0.36 T**
C	0.52 T	0.46 T	**0.37 T**

Low-Frequency Ferrite

CORE LOSS TEST – 150 mT

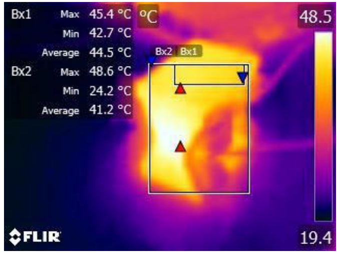
Core loss of each material has been measured and compared at 150 mT and 100 kHz.



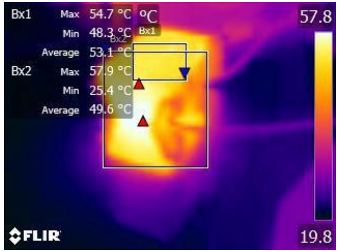
There is a difference of 1.01 W measured between manufacturer A and C.

Regarding Steinmetz model, manufacturer C exhibits lower differences between calculated and measured values as opposed to manufacturer A.

MANUFACTURER A



MANUFACTURER C

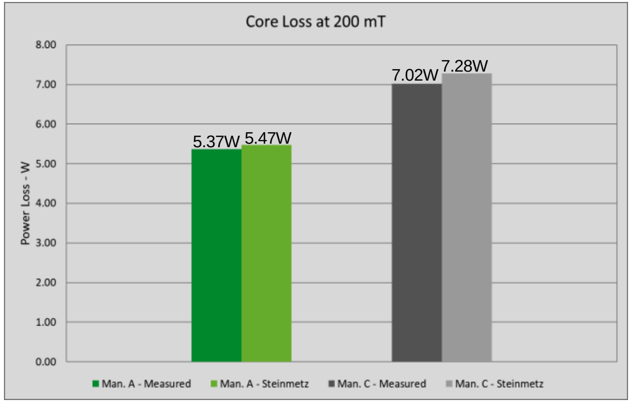


Besides, temperature in the magnetic of manufacturer C has 10 degrees Celsius higher temperature (maximum hotspot) compared to the manufacturer C.

Low-Frequency Ferrite

CORE LOSS TEST – 200 mT

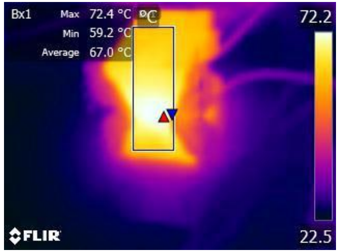
An additional test has been done at 200 mT and 100 kHz comparing the two selected materials.



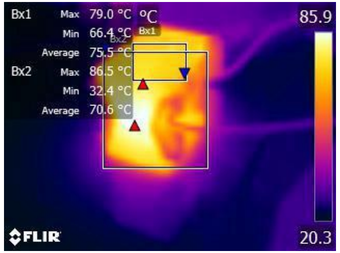
Core loss difference between manufacturer A and C was 1.65 W.

Comparing measured and calculated results, both materials has minor differences.

MANUFACTURER A



MANUFACTURER C



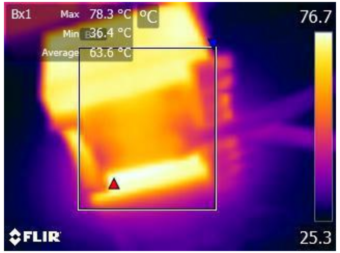
Regarding temperature, magnetic from manufacturer C has 15 ºC of maximum hotspot higher than manufacturer A.

Low-Frequency Ferrite

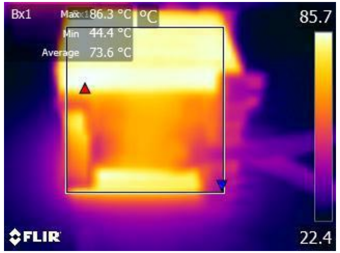
CONVERTER TEST

The temperature of each core manufacturer has been recorded and compare with each other.

MANUFACTURER A



MANUFACTURER C



For the same operating point and magnetic characteristic, changing material has an impact in the total losses and also in the temperature of the magnetic.

MANUFACTURER	Max. Temp	Conv. Efficiency
A	78.3 ºC	82.38 %
C	86.3 ºC	81.83 %

Therefore, it is concluded that both materials are not entirely equivalent.

High-Frequency Ferrite

High-Frequency Ferrite

MANUFACTURE SPECIFICATION

This material is useful for converter topologies that work at higher frequencies (like GaN or SiC boards). It offers a flat loss in a wide range of temperatures (25ºC to 100ºC) at operating frequencies up to 1 MHz.

The five materials previously chosen are compared against each other based on the datasheets provided by the manufacturers themselves.

MANUFACTURER G

MANUFACTURER H

MANUFACTURER I

MANUFACTURER J

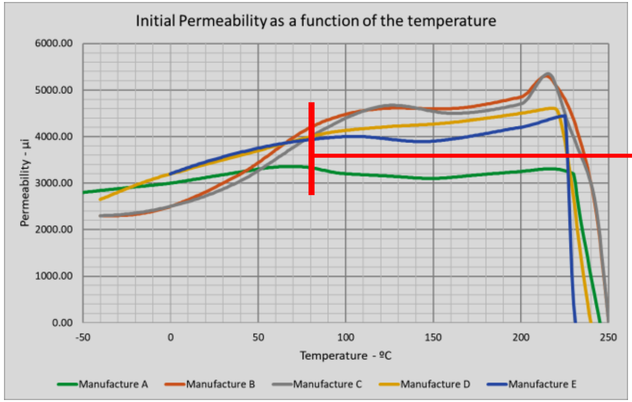
MANUFACTURER K

High-Frequency Ferrite

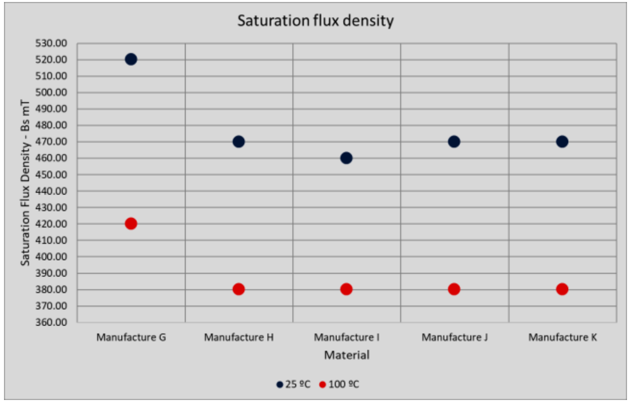
INITIAL PERMEABILITY AND SATURATION FLUX DENSITY

As seen previously, the initial permeability vs temperature and also the saturation flux density is compared among the materials.

Saturation flux density labels the maximum peak of magnetic field allowed so that the component does not reach saturation.



MANUF.	PERM
G	1776
H	1770
I	1830
J	1679
K	1780



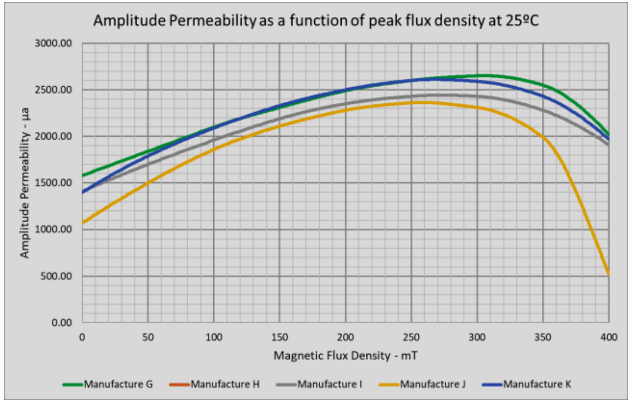
It could be seen that the behaviors of all materials are so close.

In case of the saturation, manufacturer G material has the highest value and stands out above the rest.

High-Frequency Ferrite

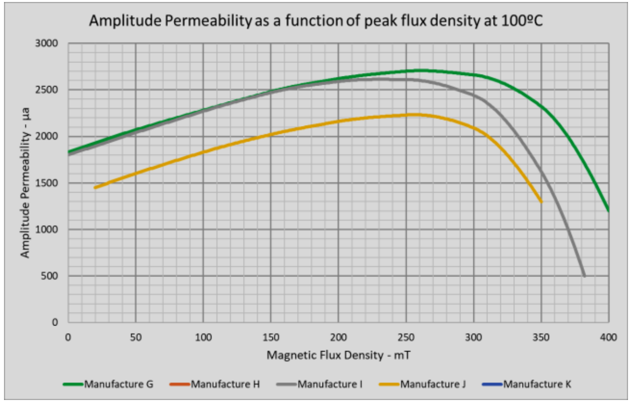
AMPLITUDE PERMEABILITY VS MAGNETIC FLUX DENSITY

Such high-frequency material has a low permeability. The amplitude permeability variation is not much larger compared to other materials.



All materials exhibit a very similar trend. Manufacturer H data is not available.

Amplitude permeability also is affected by the temperature of the magnetic component.



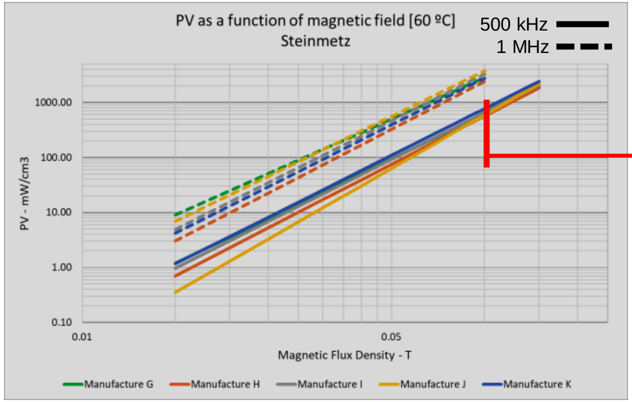
At 100 ºC, G and I materials exhibit the same behavior.

High-Frequency Ferrite

POWER LOSSES

To compare the power loss of the materials , the classical Steinmetz's equation has been used, calculating the coefficients based on the information provided by the ferrite manufacturers.

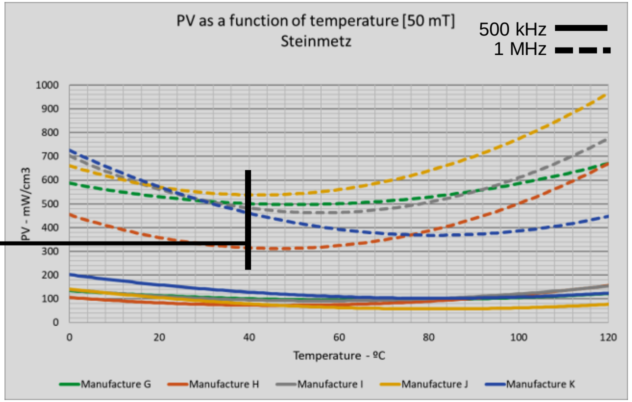
This information is in different charts that show the variation of the power losses vs. frequency, magnetic flux density and temperature.



PQ40/40 calculated losses based on manufacturer data

MANUF.	LOSS
G	12.7 W
H	11.6 W
I	13.4 W
J	12.1 W
K	15.8 W

MANUF.	LOSS
G	10.3 W
H	6.45 W
I	9.88 W
J	11.1 W
K	9.44 W



The results show that all the materials have significant differences in the power losses, hindering the possibility to exchange them with each other.

For temperatures below 80ºC and a magnetic flux density of 50 mT, H material exhibits the lowest losses.

Conclusions

- It is not straightforward to determine what materials are equivalent to each other.
- For materials that are frequently used (like the low-frequency), the information provided in the datasheet is more detailed.
- Two different approaches for power losses calculation have been proposed (Steinmetz and IGSE). For the equivalence point of view, no major differences have been found between the proposed methods.
- Low-frequency material analysis shows that there are some differences in the permeability and power losses. A and D materials are very similar, as well as B and C materials seem practically the same.
- High-frequency material exhibits more differences in permeability, saturation and also power losses. It could be concluded that these materials are not “equivalent” as well, and an analysis is required to use one of the materials instead of the other.
- Low-Frequency material saturation measured is close to the manufacturer data provided at 10 kHz, but mostly DC-DC converters works at higher frequencies, where the saturation limit is quite far from the ones provided by the manufacturers.
- Hardware validation presents a real measurement comparison between two of the five low-frequency materials. In the case example, it could be concluded that these materials are not fully equivalent, exhibit significant differences in the core losses.

References

[1] Ch. P. Steinmetz, “On the law of hysteresis”, reprint, Proc IEEE, (UK), 1993 72(2), pp. 196-221,2 1984.

[2] Jieli Li, T. Abdallah, and C. R. Sullivan, “Improved calculation of core loss with nonsinusoidal waveforms”, in Conference Record of the 2001 IEEE Industry Applications Conference. 36th IAS Annual Meeting, 2001, pp. 2203–2210.

[3] Erickson, R. W., & Maksimović, D. (2001). Fundamentals of power electronics. Norwell, Mass: Kluwer Academic.