Magnetic resilience studies for power supplies

F. Giordano[1*], C. Landi[1], A. Guatteri[1], S.Selmi[1]

TWEPP 2023, 1–6th Oct 2023, Geremeas - Sardinia (Italy)

Modern physics experiments require higher LV power to be delivered to the front-end electronics with respect to the past, this is efficiently done by placing the LV power supplies as close as possible to the detector. Unfortunately, this means that they must be robust against radiation and resilient to the magnetic fields often present to measure particles properties.

How to design a magnetic tolerant

First of all: the transformer

When the external magnetic field is of the order of few hundreds mT it is not possible to use common ferrite cores, as their high permeability and low Bsat would lead them to saturation: the only possibility is to use low permeability/high Bsat materials which do not excessively concentrate the field inside them, limiting saturation to the outermost layers of the core.

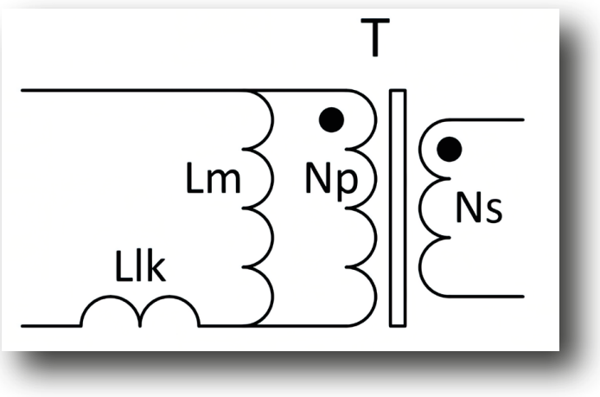
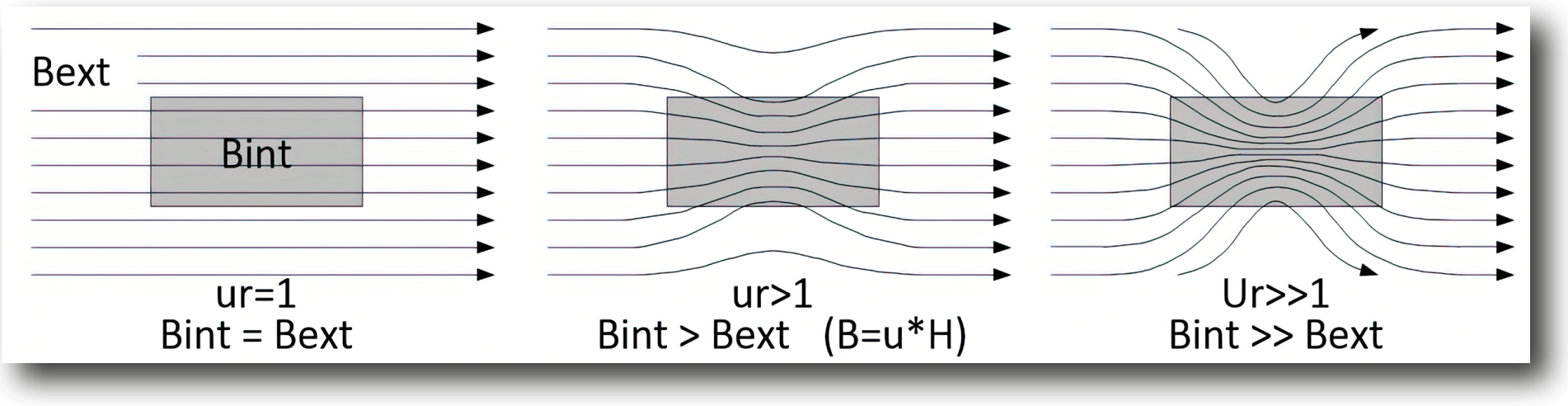


Figure 1 (left): Graphical depiction of an ideal transformer.
Firugre 2 (right): Magnetic flux lines of a ferrite close to saturation.
Figure 3 (bottom): One of the inductor used for the design.



The transformer we obtained presents some compromises, such as low magnetic inductance, and high leakage flux: these characteristics influence the design of the converter.
Low inductance means high magnetizing currents and the need for high working frequencies; high leakage flux means less primary-secondary coupling, less power transfer capability, high equivalent leakage inductance, irradiated noise, need for shielding, eddy current losses.
A toroidal core shape usually helps reduce flux leakage, although it can create other problems in winding and shielding.
In general, the design of such a transformer is the most critical part of the converter design, and it is always a matter of finding the best balance between the various compromises to be accepted.
Some solutions are being studied for shielding the external field, to be more flexible in the choice of core materials: this may mitigate the above issues a bit.

Second: the electronics around it

Since the transformer has important parasitic components, not all converter topologies are well suited for driving it: reducing switching losses is mandatory, as the working frequencies will have to be rather high. Resonant topologies usually performs well, as the dispersion component of the primary inductance is advantageously exploited and made to resonate with an adequate capacitor, so as to store a certain quantity of energy at each switching cycle; this energy is then used to obtain the ZVS or ZCS of the electronic switches, thus limiting their switching losses and noise. Good results has been obtained by using LLC converters and resonant clamp converters.

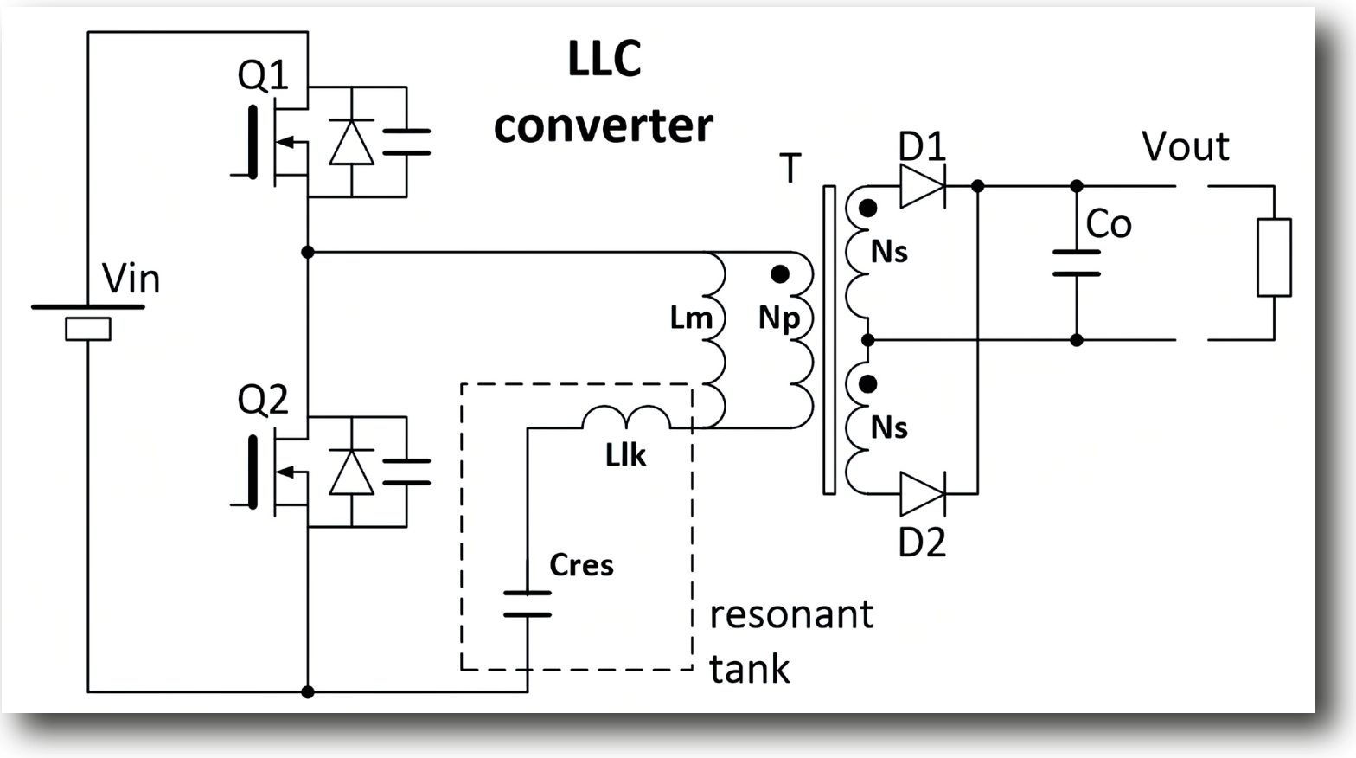
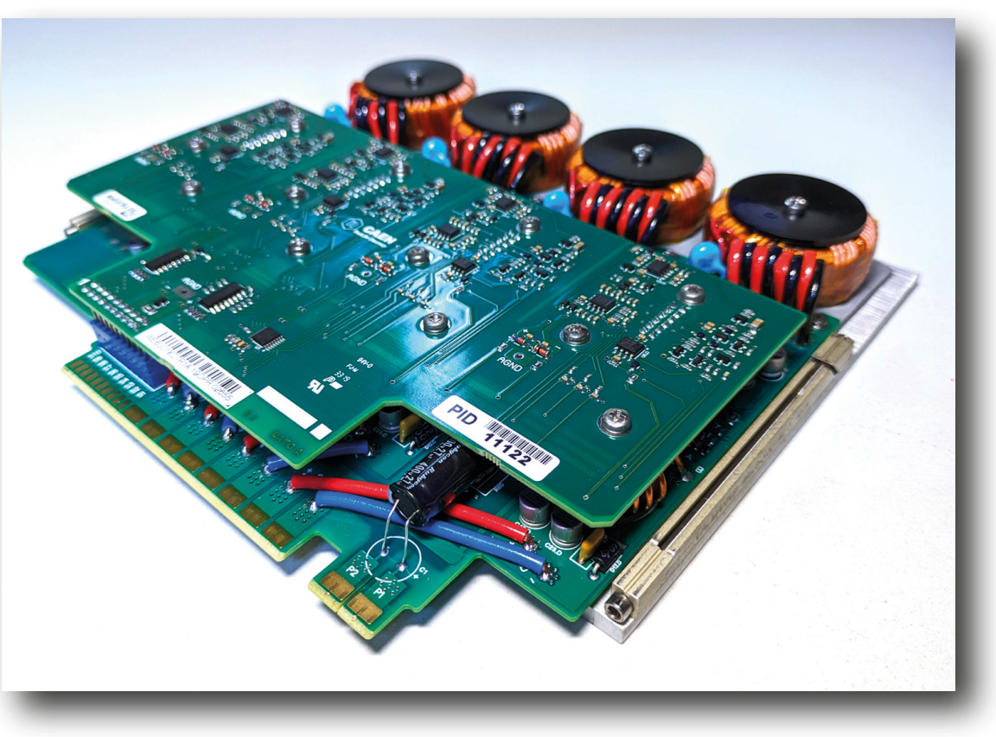


Figure 4 (left): Example of LLC converter.
Firugre 5 (right): Picture of the actual module designed for the BRIC. There are four main inductors as there are four LV channels per plate.



LASA module testing

We have assembled a small converter (see Figure), with the same components and characteristics of the full BRIC so we could easily place it inside the magnet used for the test (that as a 20 cm aperture).
During the test we have performed various measurements changing the converter characteristics like Vin and Vout to find an optimal working point; then we have changed the orientation of the field w.r.t. to the inductor axis.
As shown in the figures there is a substantial difference in the efficiency when the field is perpendicular to the main toroid axis or then is parallel. The worst case is when the field is perpendicular to the toroid axis with an efficiency lost as high as 10% (overall 80%) at 0.8 T making the convertor hardly usable.

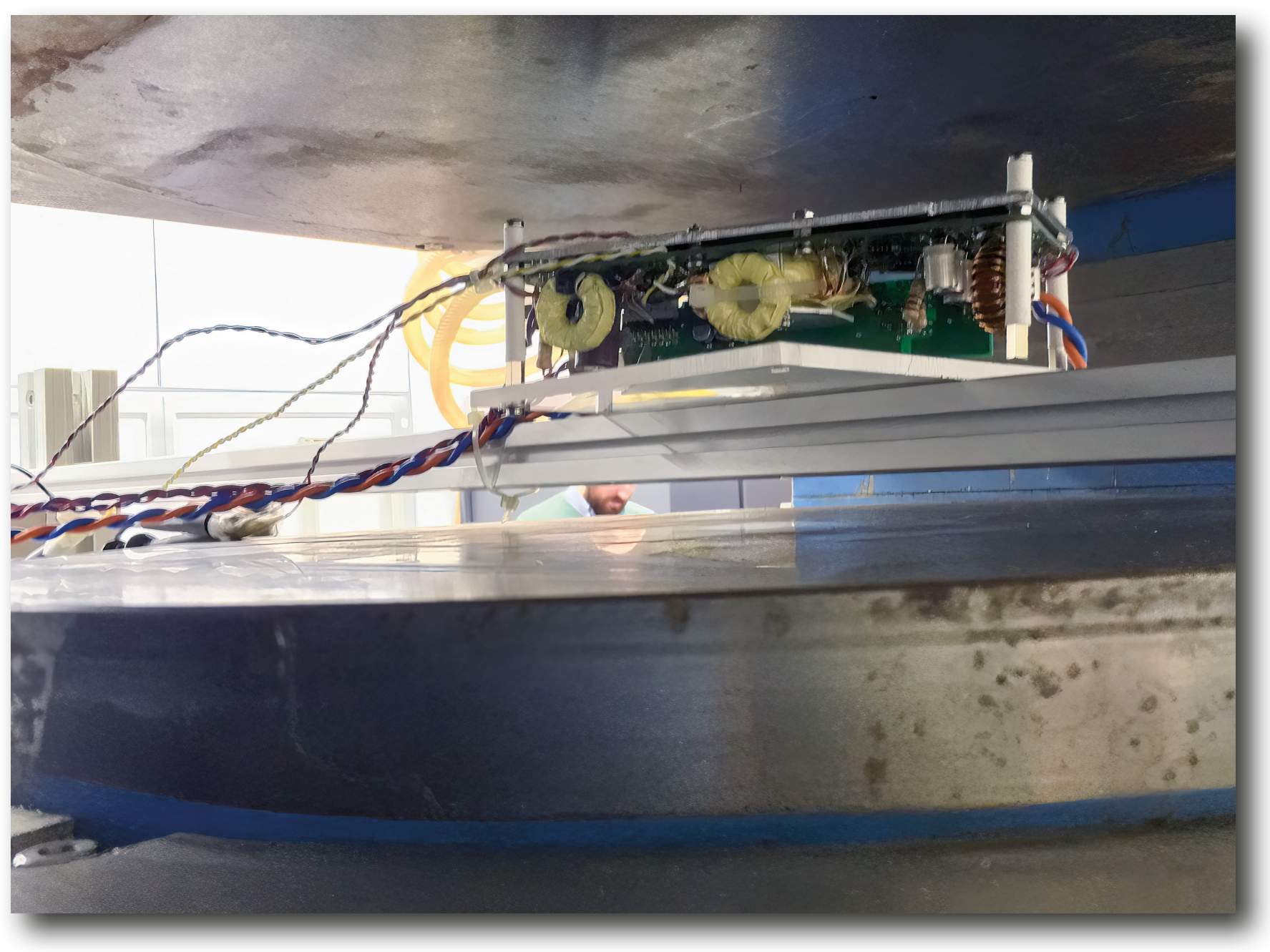


Figure 9: Picture of the channel during the test performed inside one of the magnet of the INFN-LASA.

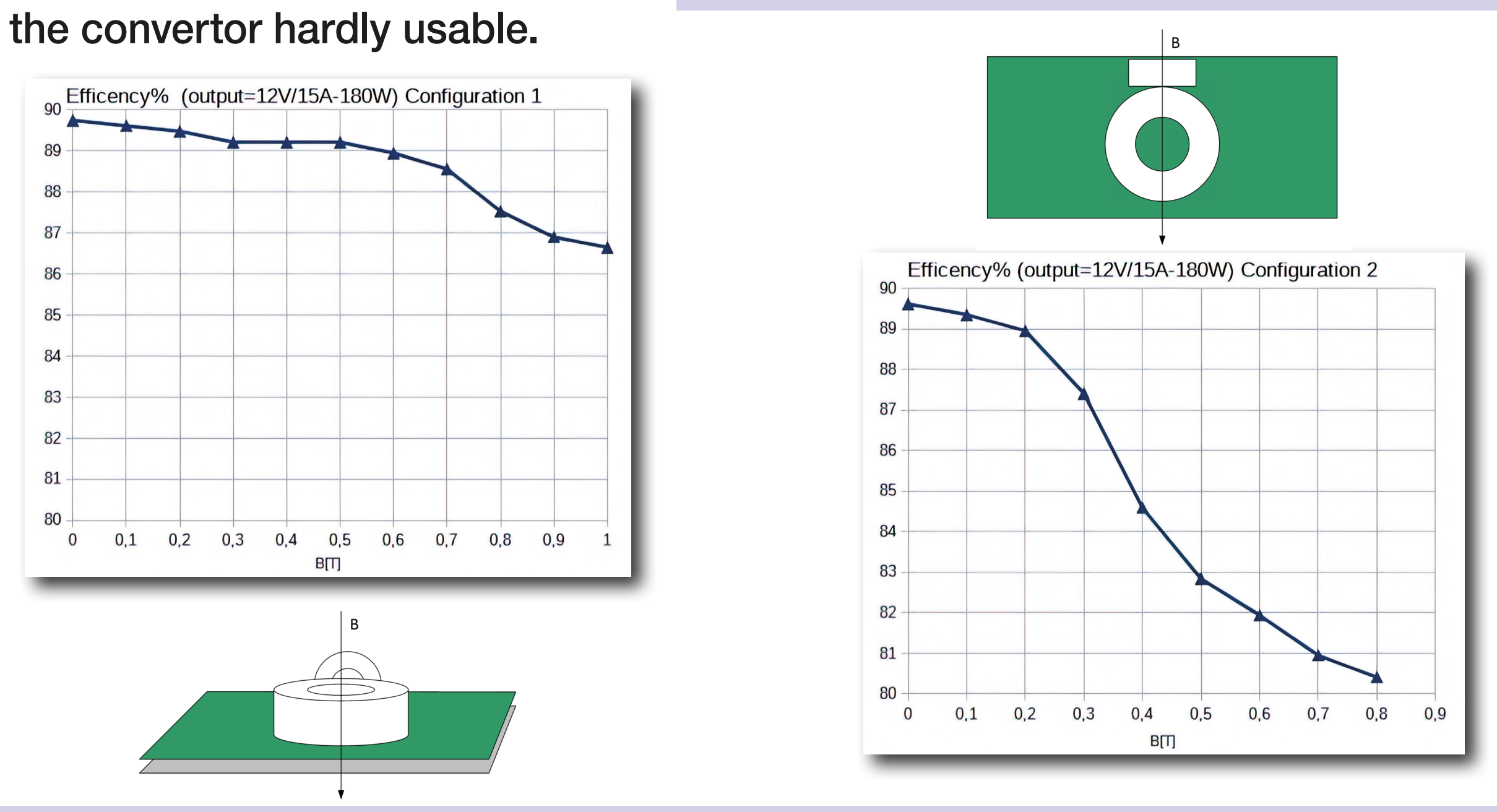


Figure10: On the left a plot showing the channel efficiency vs magnetic field where the field is parallel to the main inductor axis of symmetry, on the left the megnetic field is perpendicular to the main inductor symmetry axis. It is cleary visible that the efficiency lost is higher when the magnetic field is applied perpendicularly to the axis of the inductor.

LASA test with shielding

One technique to improve the efficiency of the module is to shield the inductors, so that their properties are more stable with increasing magnetic fields.
Ferromagnetic shielding have long been used to trap the magnetic field lines away from a sensitive piece.

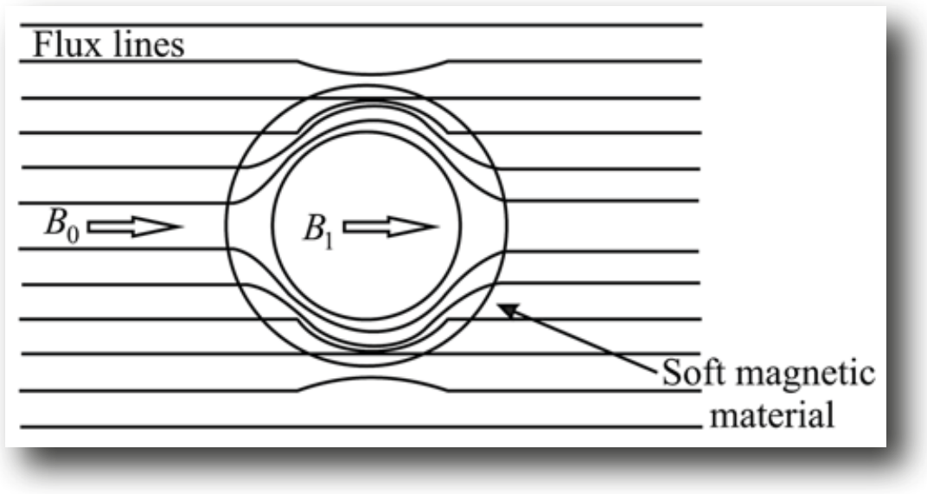


Figure 6: Graphical view of the magnetic flux lines and their behaviour in proximity of a magnetic material. Inside the field B1 is weaker if not totally absent with respect to B0.

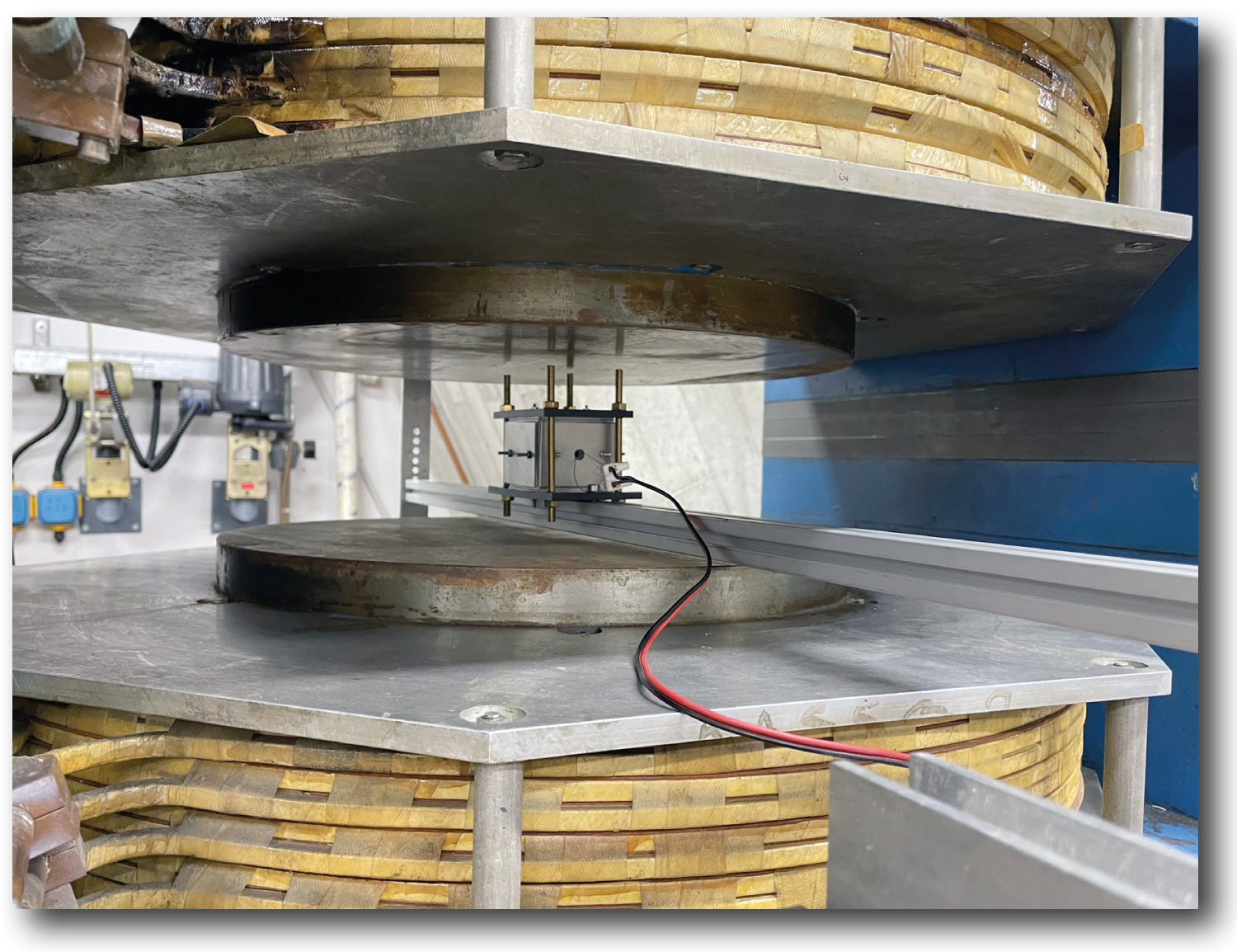


Figure 7: Picture of the enclosure used for the test while placed between the magnet plates.

We have made a small enclosure (see Figure 3) where to put a toroid of which to monitor the inductance. Within the enclosure the toroid was fixed, but we could orientate the box to have the magnetic field lines whether perpendicular or parallel to the symmetry axis of the toroid. Externally various plates of different thicknesses and materials can be attached.
We have tried a ferromagnetic shield in two thicknesses: 1 and 3 mm; and we also tried a diamagnetic material to use its reversed field to mitigate the main one. Another variable we have looked into is the magnetic permeability of the inductors. The results are summarized in the following plots.

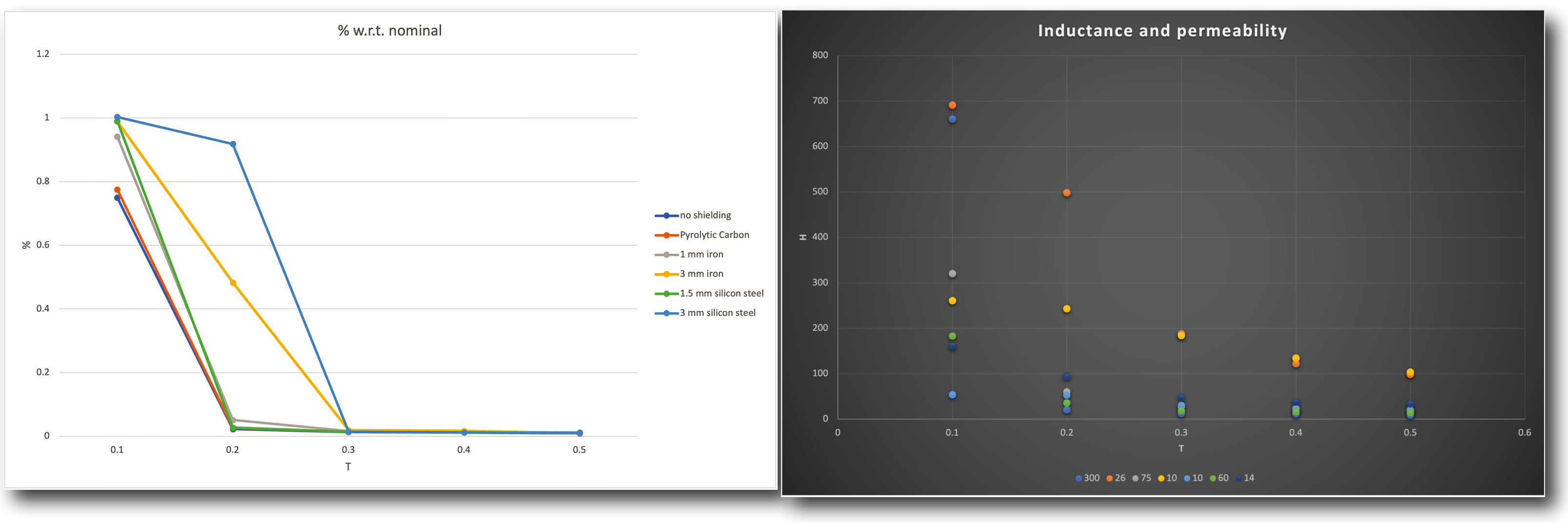


Figure 8: On the left a plot shows the variation of the inductance with respect to nominal vs magnetic field: for the inductor with no shield, with a diamagnetic shielding or with 1 and 3 mm of soft iron shields. On the right The variation of the induction at various field strenght, each color represents a different induction with a different magnetic premeability.

BRIC test at CERN

Bric (B & Rad tolerant Intermediate Converter) is a project developed to power the ATLAS New Small Wheel detectors, which required the power supplies to be installed directly on the detector.
The module is designed to receive 300 Vdc input and provide 8 independent regulated power channels of nominally 12V/180 W each, and to sustain a maximum external magnetic field in the order of 5-600 mT.
4 of these modules can be inserted into a liquid-cooled crate, which is fixed to the NSW structure.
To demonstrate its ability to operate at nominal power under a magnetic field even above the specified one, several tests were conducted at CERN's magnet Goliath.

Figure 12: BRIC water cooled crate, on the left a detail of the inside with cooling pipe visible and on the right the crate mounted with all panels.

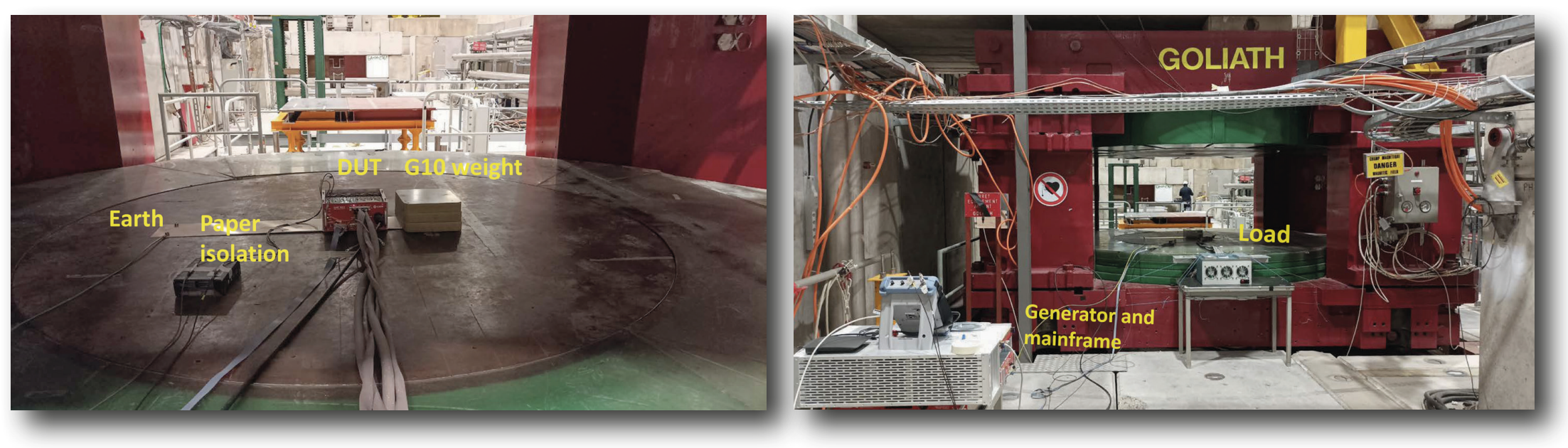


Figure 11: Picture of the large magnet Goliath at CERN on the left and a detail of the Device Under Test (DUT) on the right. Also some other equipment used during the tests is shown as the generator, the loads, cables, etc.

In Figure 13 the scope plot of current and voltage waveform at the switching node of transformer: with no external magnetic field applied and 1300 mT external magnetic field applied. The external magnetic field changes the transformer magnetic parameters, and the resonant topology of the circuit makes it working at different frequency and primary current; anyway the converter is designed to sustain it. Efficiency (see Figure 15) is sensitive to this variation, but it is still around 80% at maximum nominal field. Water cooling helps to keep temperatures of all electronic and magnetic component under control.

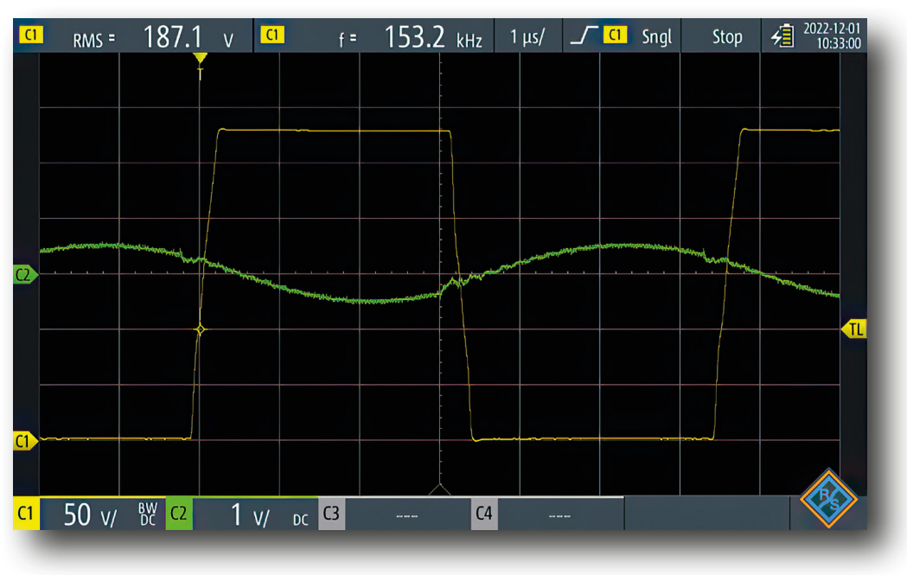
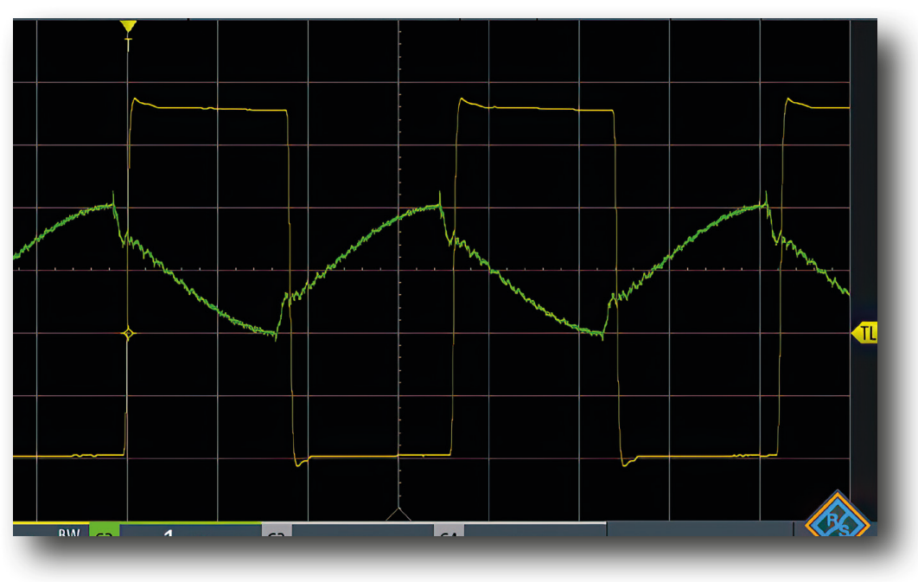


Figure 13 (top): Voltage (yellow) and current (green) as measured on the switching node of the trasformer at 0 mT.
Figure 14 (bottom): Voltage (yellow) and current (green) as measured on the switching node of the trasformer at 1300 mT.



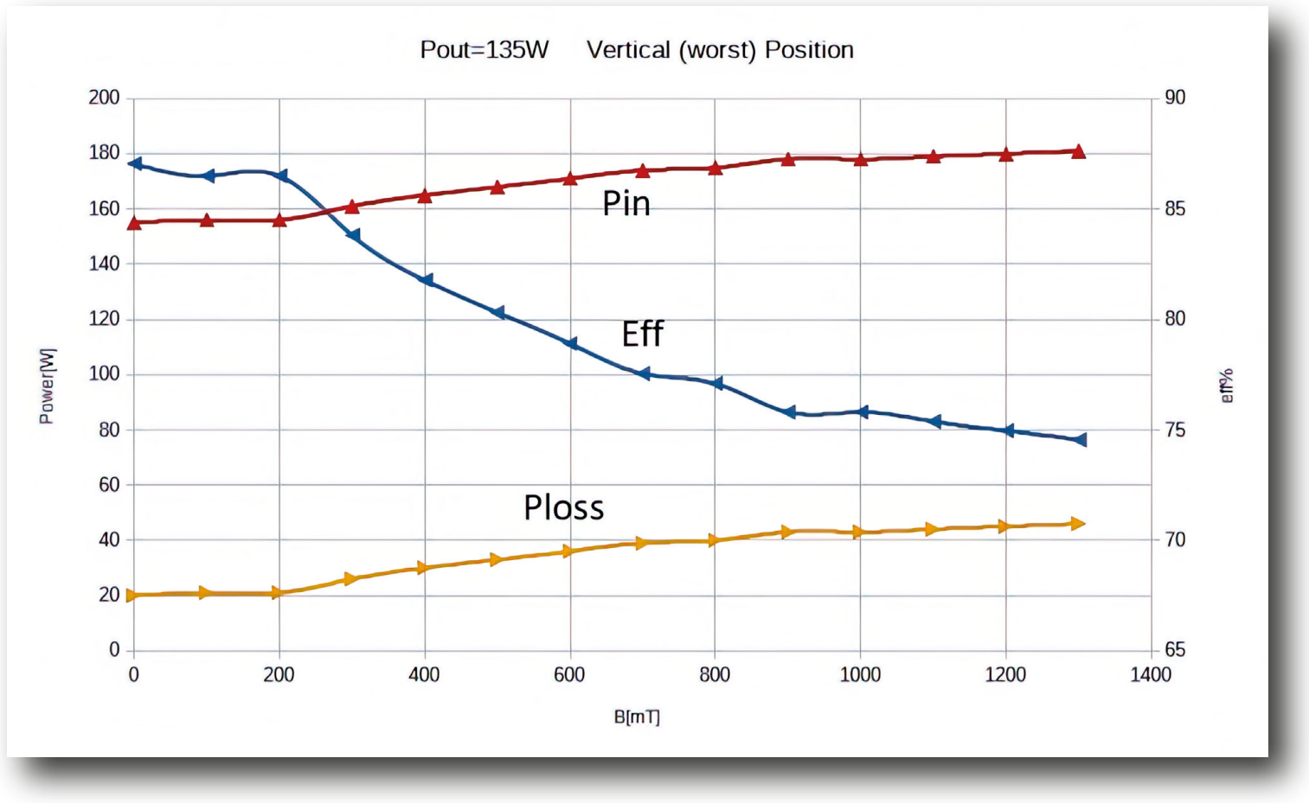


Figure 11: Efficiency and power transver plot vs magnetic field for various Vin. We can see ho the efficiency loss and power loss became evident after 600 mT.

[*] f.giordano@caen.it

[1] CAEN s.p.a. - Italy

CAEN Electronic Instrumentation

Measurements were done in collaboration with personnel of INFN Pavia and Pavia University: D. Calabro', G. Giunta, A. Lanza, M. Pirola and E. Romano.