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Feasibility study of a cryogenic power supply for superconducting DC devices

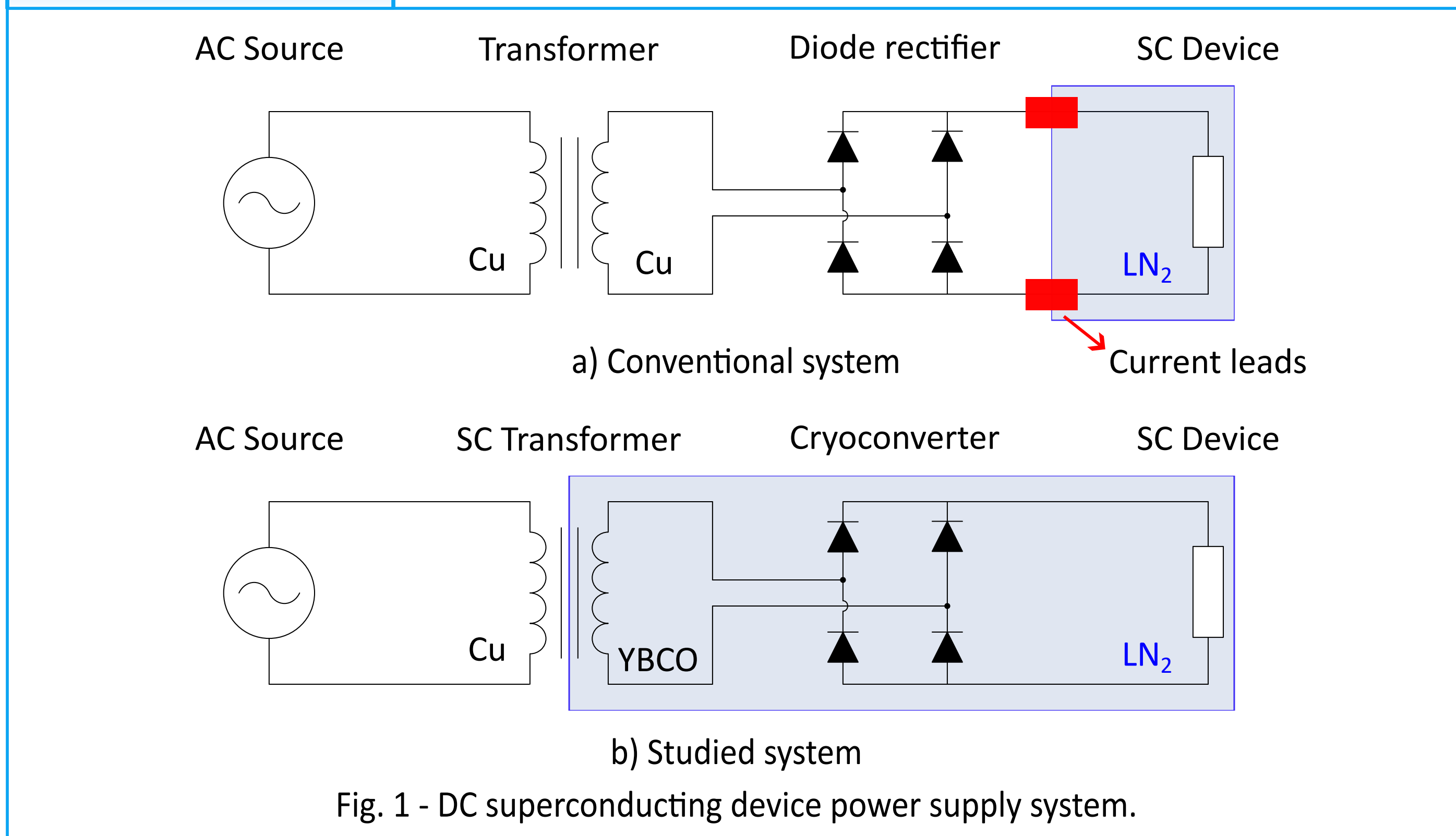
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Purposes

- Alternative option to **dispense the current leads**, responsible of high losses in superconducting systems [1].
- Design of a **superconducting transformer** with its **diode rectifier** operational at cryogenic temperature.

System design



Superconducting transformer

Double pancake coil

- A **coil winding configuration** where two pancake coils are stacked on top of each other.
- After the coil characterization in LN₂, we measured a **critical current of ~ 40 A**.

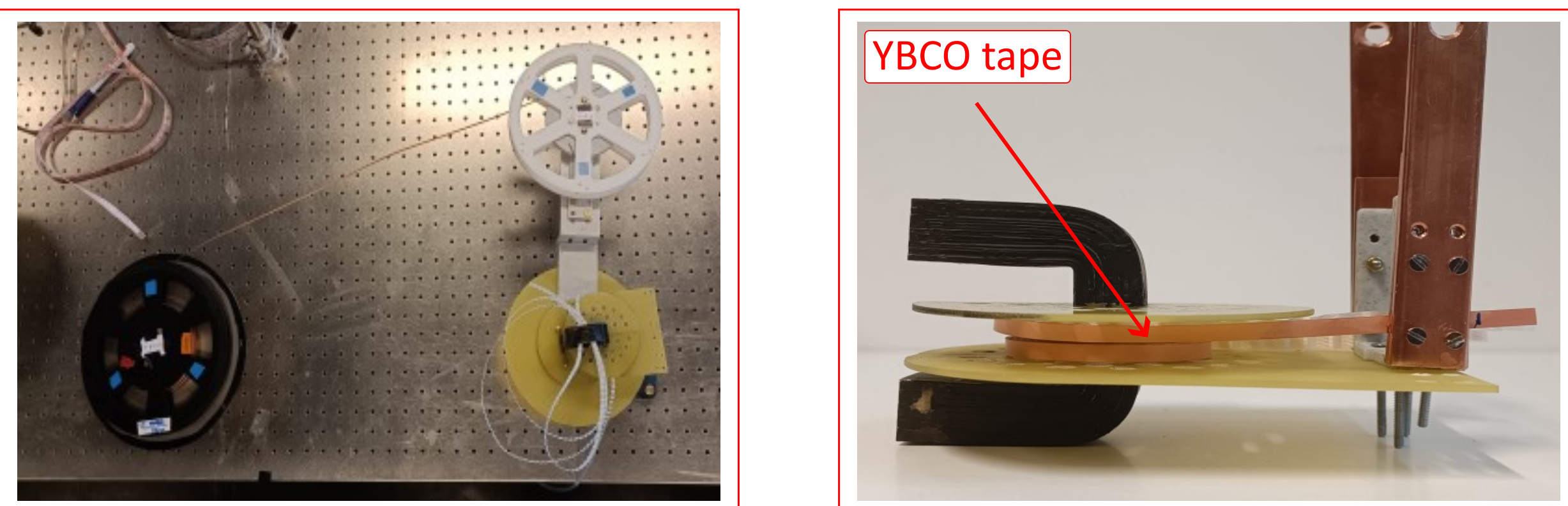


Fig. 2 - Realization of the SC double pancake coil.

Transformer test

- The SC transformer consists of the DPC as secondary winding, separated from the primary copper winding by an **airgap of 4mm thick plastic** serving as cryostat to retain the LN₂.

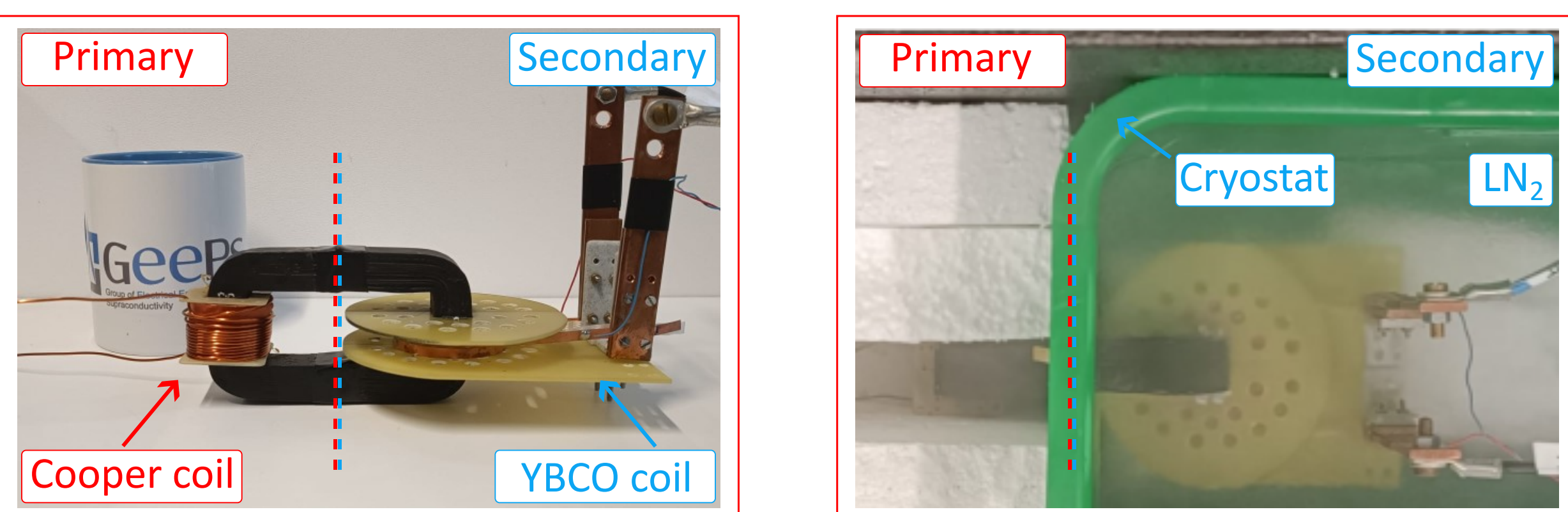


Fig. 3 - Transformer prototype.

- Following an equivalent circuit of a single-phase transformer (Fig.4), **open-circuit** and **short-circuit tests** were performed to obtain the **transformer parameters** (Tab.1).

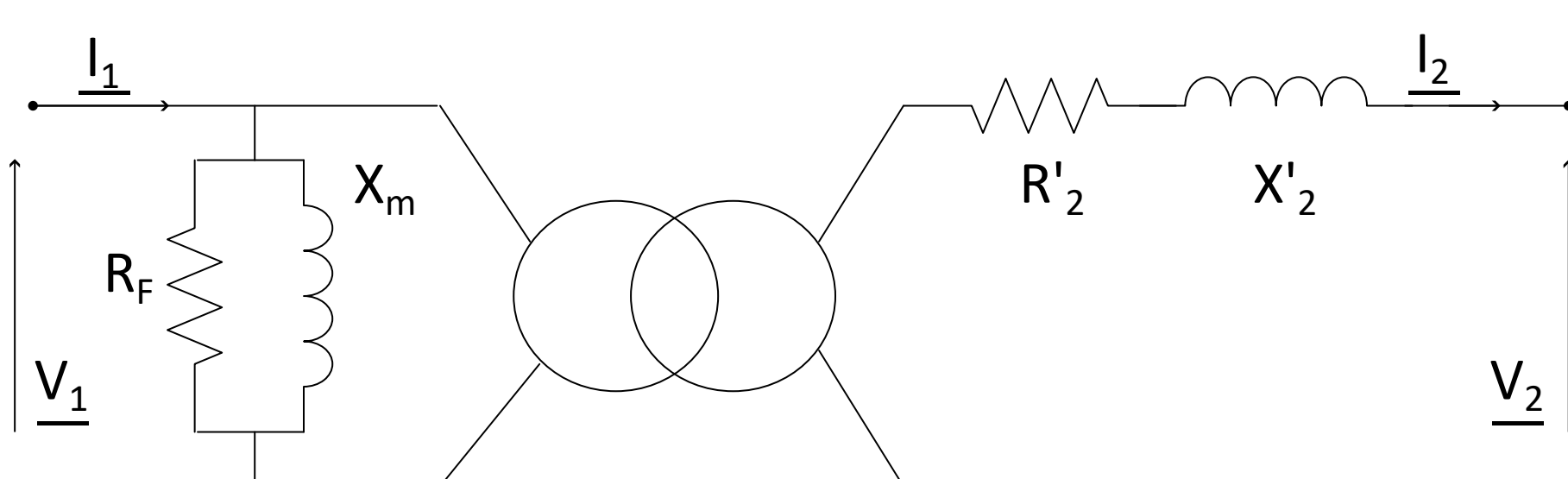


Fig. 4 - Single-phase transformer equivalent model.

Tab.1 - Transformers parameters

	V ₂ /V ₁	η _t [%]	R _f [Ω]	X _m [Ω]	R' ₂ [Ω]	X' ₂ [Ω]
Conventional	0.11	1.5	1.13	0.42	3.76	4.24
Superconducting	0.09	25.8	1.74	0.38	0.05	0.16

Note: Efficiency does not take into account the cooling system power (i.e. η_t=P₂/P₁).

Cryoconverter

Diode characterization

- Different semiconductor technologies **behave differently** at cryogenic temperatures [2].
- **Some diode technologies are more suitable** for operation at cryogenic temperature.

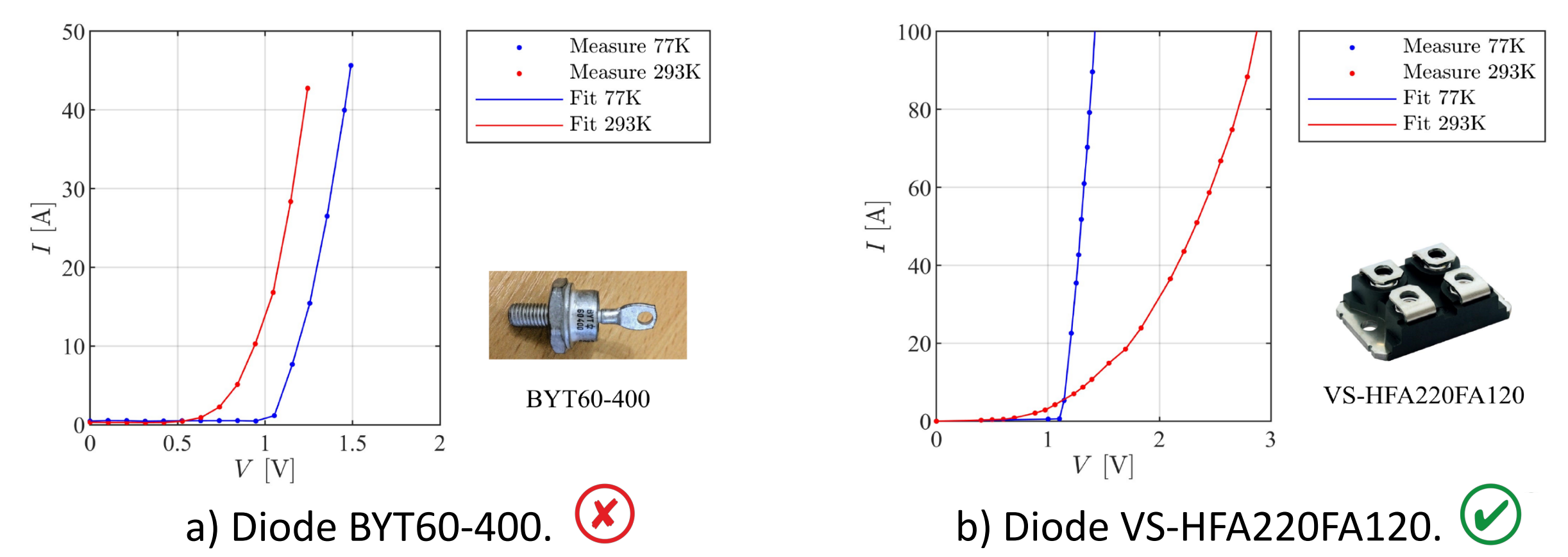


Fig. 5 - Measured diode current-voltage curve.

Cryoconverter test

- The diodes with favorable behavior in LN₂ are connected as 4 diodes **single-phase rectifier** on top of an aluminum heatsink to improve heat dissipation.
- A sinusoidal voltage of 50 V RMS was applied and the efficiency was studied for several load and hence power.

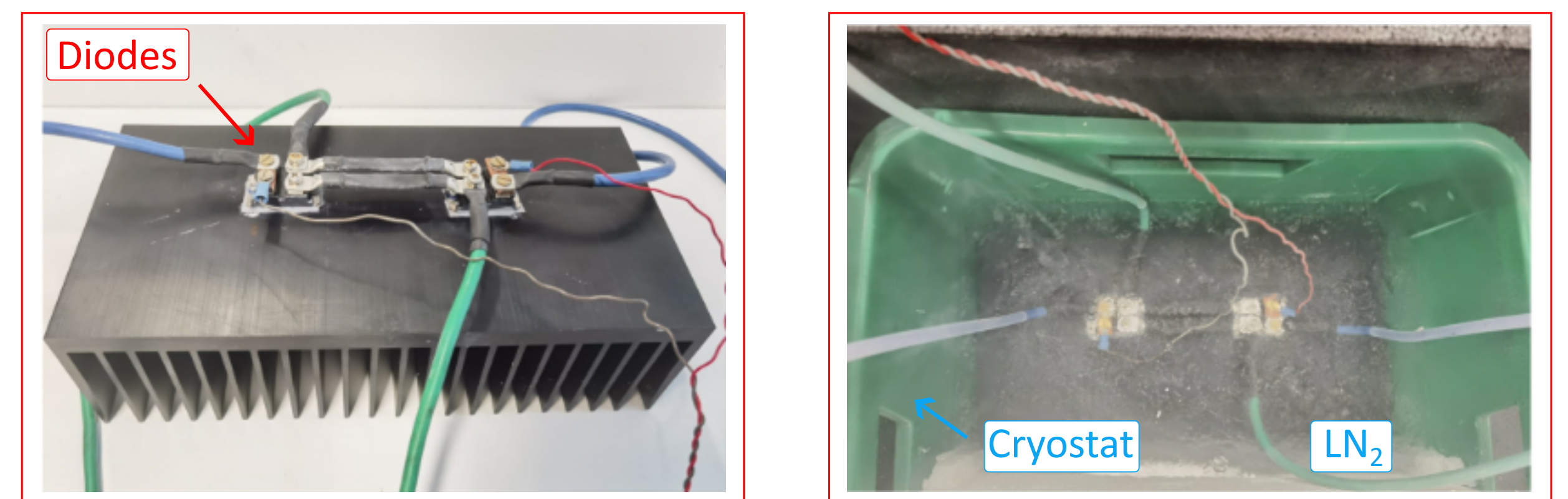


Fig. 6 - Diode bridge test at cryogenic temperature.

- Diode rectifier **losses reduced by an average of 27.6%**.
- Diode rectifier **efficiency improved by 2%** for a DC power of 1kW.

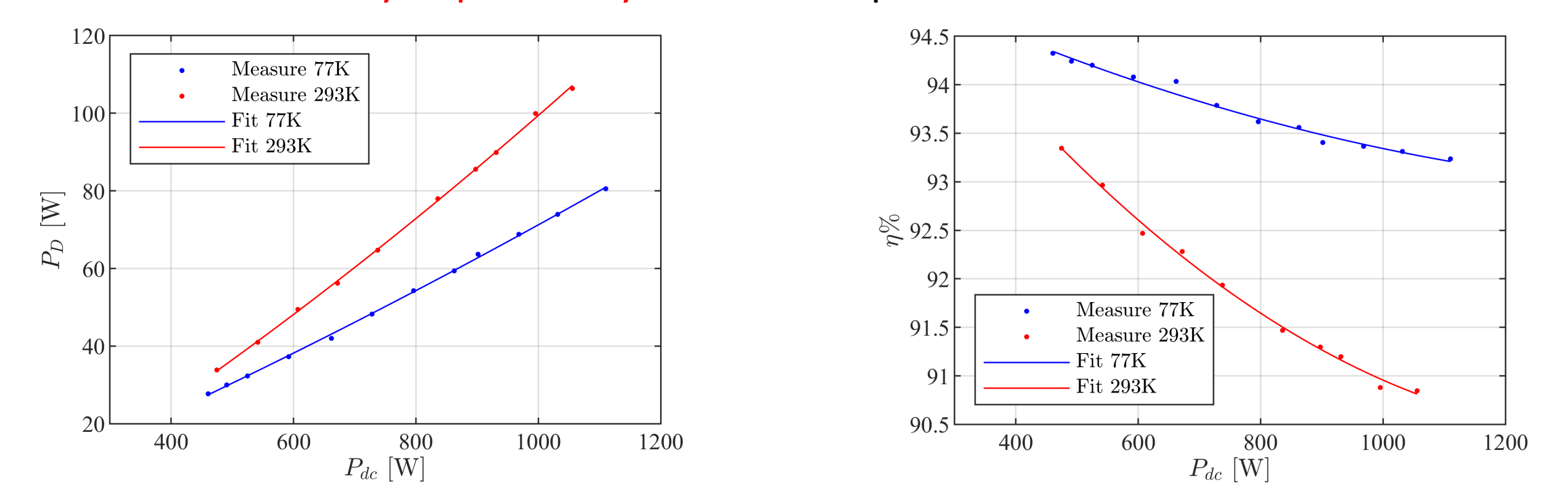


Fig. 7 - Cryoconverter performances at room and cryogenic temperatures.

Conclusion

- Development of the superconducting **double pancake coil**.
- Realization of a **first superconducting transformer**.
- Power transfer through the cryostat between different temperatures.
- **Characterization of diodes** at cryogenic temperature.
- Realization and test of the **diode rectifier** operational at cryogenic temperature.

Next steps

- Further **assembly of the system** improving the output level of the transformer to 1kW.
- **Improvements of the cryostat** for the reduction of the airgap.
- Make a **techno-economic analysis** between systems under study.

References

- [1] A. Ballarino, "Current Leads, Links and Buses," *Proc CAS-CERN Accel. Sch. Supercond Accel.*, pp. 547–558, 2013.
- [2] A. Elwakeel, Z. Feng, N. McNeill, M. Zhang, B. Williams, W. Yuan, "Study of power devices for use in phase-leg at cryogenic temperature," *IEEE Trans. Appl. Supercond.*, vol. 31, no. 5, pp. 1–5, Aug. 2021.

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