STATUS OF MAGNETS FOR ALBA II PROJECT: DESIGN, PROTOTYPING AND PRODUCTION PLANS

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Abstract

The upgrade project of the ALBA Synchrotron Light Source is gaining momentum following the official approval of the required funds at the end of 2025. The design of the magnets for the new ALBA II storage ring began in 2021 with the launch of a comprehensive prototyping program aimed at developing and validating the various magnet types required by the new multi-bend achromat (MBA) lattice. The first prototype magnets became available at the end of 2025 and are currently being characterized at ALBA's magnetic measurements laboratory to assess their performance against the design specifications, as well as to investigate critical aspects such as magnetic cross-talk and mechanical integration between neighboring magnets. In parallel with prototype fabrication, the magnet designs have continued to evolve to keep pace with the successive refinements of the ALBA II lattice over the past years. The lattice is now approaching its final configuration, and together with the lessons learned from the prototyping campaign, this will enable the completion of the magnet designs during 2026.

INTRODUCTION

The ALBA II project will transform the existing ALBA storage ring, in operation since 2012, into a fourth-generation synchrotron light source by implementing an ultra-low emittance multi-bend achromat (MBA) lattice [1]. A key element of this upgrade is the development of a new set of storage ring magnets capable of meeting the stringent optical and integration requirements imposed by the compact MBA layout, while maintaining compatibility with the existing tunnel and beamline infrastructure.

An initial set of design studies and conceptual solutions for the ALBA II magnets was reported previously [2], focusing on the definition of magnet requirements and the development of first resistive and permanent-magnet-based prototypes. Since then, the project has entered a new phase in which detailed engineering, prototyping, and experimental validation are being carried out in parallel with the convergence of the ALBA II lattice toward its final 5BA configuration. The present paper provides a comprehensive status update of this program, covering design evolution, prototyping results, magnetic measurements, and production planning.

EVOLUTION OF LATTICE AND MAGNET REQUIREMENTS

The reference lattice for ALBA II has evolved in recent years from the initial 6BA concepts toward a more flexible 5BA solution [3]. This evolution has led to updated requirements for all magnet families (dipoles, reverse bends, quadrupoles, sextupoles, and correctors). In addition, octupoles were introduced at the end of 2024 as a necessary element to improve the dynamic aperture [4].

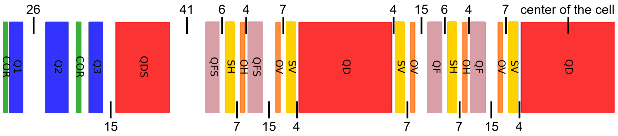

Figure 1: Schematic view of half a cell of the 5BA lattice designed for ALBA II. The quadrupole triplet on the left side is facing a straight section, and the dipole on the right side sits in the middle of the cell. Numbers indicate distances in [cm] between the effective lengths of each pair of magnets.

The current set of magnet requirements is summarized in Table 1, while Fig. 1 shows the magnet distribution within one cell [5]. The lattice remains extremely compact, with magnet-to-magnet distances as small as 40 mm. This imposes significant challenges in terms of both mechanical integration and magnetic cross-talk between neighboring elements.

At present, most magnets are foreseen to use resistive technology, i.e. iron-dominated yokes with water-cooled copper coils. This choice is driven by the high degree of tunability required across the different magnet families. Two notable exceptions are identified:

- The QDS dipoles (outer dipoles of each 5BA cell), for which tunability is less critical and which will therefore be based on permanent magnet (PM) technology.
- The QD superbend magnets, designed for beamlines requiring higher photon critical energy. These will combine a PM-powered high-field (> 3 T) central pole with coil-powered side poles to preserve tunability.

Compared to the initial design described in [2], one important modification is that each sextupole will now include both horizontal and vertical dipolar correctors. As a counterpart, skew quadrupole correctors will be relocated from sextupoles to octupoles.

OVERVIEW OF THE PROTOTYPING PROGRAM

To address the main design challenges, ALBA launched a comprehensive prototyping program in 2021 covering all critical magnet families foreseen for ALBA II. These prototypes are being procured through industrial contracts.

Due to the continuous evolution of the accelerator lattice, each prototype has been designed according to the lattice version available at the time of contract definition. As a

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Table 1: Magnet requirements for 5BA lattice for ALBA II upgrade. The symbol L_{eff} stands for the effective length of each magnet, and the symbols B, G, S, and O correspond to its dipolar, quadrupolar, sextupolar, and octupolar strength, respectively (i.e. $B(x) = B + Gx + Sx^2 + Ox^3$).

Function	**Types**	**# per cell**	**# total**	L_{eff} [mm]	B [T]	G [T/m]	S [T/m^2]	O [T/m^3]	**Aperture** [mm]
Bending	QD	3	48	1050	1.05	-13.0			20
	QDS	2	32	605	1.05	-14.4			20
Rev. Bend	QF	4	64	160	-0.52	$+64.7$			30
	QFS	4	64	160	-0.49	$+69.3$			28.7
Quadrupole	Q1	2	32	150		≤ 105			20
	Q2	2	32	250		≤ 110			20
	Q3	2	32	150		≤ 105			20
Sextupole	SH	4	64	100			≤ 5250		23
	SV	7	112	100			≤ 5250		23
Octupole	OH	4	64	50				$\leq 1.67\text{e}5$	24
	OV	7	112	50				$\leq 1.67\text{e}5$	24
Fast Corr.	CORR	4	64	40	0.55 mrad in both planes				45
Total		45	720						

result, prototype designs differ from the final configurations that will be implemented in ALBA II. Nevertheless, the lessons learned remain fully relevant for series production for several reasons:

- At least one prototype is being manufactured for each magnet type, and in some cases multiple technological solutions are being explored.
- The required magnetic strengths have remained largely stable across lattice versions.
- The vacuum chamber geometry has not changed significantly, implying stable aperture requirements throughout the design process.

Resistive Magnet Prototypes

Most resistive magnet prototypes were procured through a call for tender launched in February 2024, covering all magnet types listed in Table 1, except octupoles. The designs were based on parameters described in [2]. All contracts were awarded to ANTEC Magnets SLU and signed in June 2024.

To date, prototypes for the fast corrector (CORR), a quadrupole (Q3), and a reverse bend (QF) have been delivered and are currently under characterization at the ALBA Magnetic Measurements Laboratory. The remaining prototypes are expected by June 2026.

Although these magnets were designed for a 6BA lattice, they already incorporate key features expected in the final designs:

- Two-layer coil configurations to minimize distances between adjacent coils.
- Embedded coil concepts within the iron yoke, tested in one of the bending magnets.
- Apertures compatible with a circular vacuum chamber with an external radius of 18 mm.

Following the introduction of octupoles in late 2024, a dedicated prototyping effort was initiated. Two variants have been developed: one combining water-cooled main coils with air-cooled correctors, and another fully air-cooled version; the main parameters of the two designs are listed in Table 2. A call for tender was launched in October 2025, and a contract was signed with Sigmaphi in February 2026. The octupole prototypes are expected to be delivered by mid-2027.

Table 2: ALBA II Octupole Prototypes Parameters

Parameter	**Unit**	**Value**			
L_{eff}	[mm]	50			
Int. octupole	[T/m^2]	6671			
Int. skew quad.	[T]	0.25			
Yoke parameters					
Aperture diam.	[mm]	24			
Yoke length	[mm]	45			
Yoke width	[mm]	578.5			
Yoke height	[mm]	578.5			
Pole-to-pole vertical distance	[mm]	7			
		Water prototype		**Air prototype**	
Coil parameters		Main (water)	Corr (air)	Main (air)	Corr (air)
# turns		44	52	150	46
# layers		2	2	6	2
Conductor dimensions	[mm]	3x3∅2	4x1	4x1	4x1
Total current	[A·turn]	617.61	250	617.61	250
Current	[A]	14.04	4.81	4.12	5.43
Curr. density	[A/mm^2]	2.50	1.20	1.03	1.36
Power	[W]	53.46	8.79	20.51	12.80
Total length	[mm]	76.2		75.8	

Figure 2 shows a view of the different resistive magnet designs that are being developed under the prototyping program.

Permanent Magnets Prototypes

Permanent magnet technology is being explored for applications where reduced tunability is acceptable or where performance gains justify increased complexity. Two designs were developed along 2024 using one of the first versions of the 5BA lattice as a reference.

The first corresponds to a pure-PM version of the QDS dipole, using NdFeB ($B_r = 1.35$ T) blocks, combined with NiFe shims to compensate thermal effects and mechanical tuners allowing manual field adjustment within a ±2% range.

The second design is the QD superbend, which incorporates a high-field central pole made of permendur and

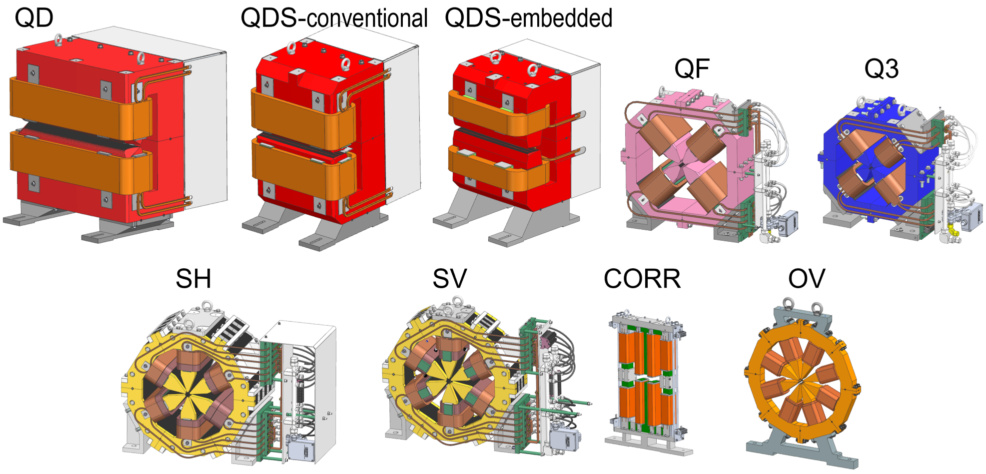

Figure 2: View of resistive magnet designs being developed under ALBA II prototyping program.

surrounded by NdFeB blocks. The pole geometry is optimized to concentrate magnetic flux and maximize the field. Partial inclusion of NiFe material ensures thermal compensation. On each side of the central pole, coil-powered curved poles provide the remaining integrated field and focusing. To minimize the overall magnet length and the spacing between the central and the low-field poles, coils with embedded configuration are used.

The main parameters of the PM prototypes are summarized in Table 3. A call for tender was launched in September 2024, and both prototypes were awarded to Danfysik A/S in February 2025. The designs have since been refined in collaboration with the manufacturer, and the final versions are shown in Fig. 3. The prototypes are currently in the assembly phase and are expected to be delivered in June 2026.

Table 3: ALBA II PM Prototypes Parameters

Parameter	unit	QDS-PM	QD-superbend
L_{eff}	[mm]	605	1050
Int. Field	[T·mm]	633	1088
Int. Gradient	[T]	−9.65	−13.65
Local field	[T]	1.05	0.9 (low field) 3.2 (high field)
Aperture	[mm]	20	20 (low field) 10.2 (high field)
PM material		NdFeB	NdFeB
Operating current	[A]	—	140

FINAL DESIGN AND PRODUCTION PLANNING

In parallel with prototyping activities, magnet designs continue to be refined to follow the evolution of the lattice. This includes detailed studies of magnetic cross-talk using 3D simulations, as well as the integration of photon beam extraction channels within the magnetic structure.

The ALBA II lattice is expected to be finalized by mid-2026. Once the magnet requirements are fixed, the final designs for all magnet families will be completed, incorporating feedback from prototype manufacturing and testing.

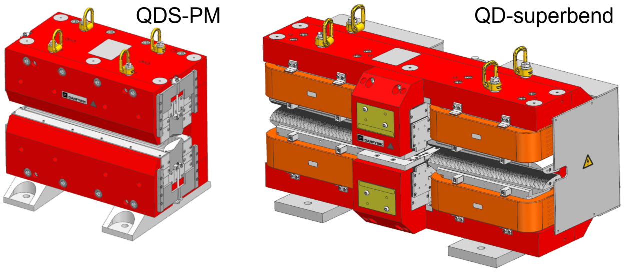

Figure 3: View of the two ALBA II magnet prototypes which incorporate PM magnet blocks, currently being manufactured by Danfysik.

Particular attention is being given to ensuring reproducibility of magnetic performance, as well as compatibility with installation and alignment procedures.

Technical specifications for series production are expected to be completed by early 2027, with industrial contracts foreseen for mid-2027.

SUMMARY AND OUTLOOK

The ALBA II magnet program has progressed from initial conceptual design to an advanced phase of prototyping and validation, closely aligned with the convergence of the lattice design. The availability of the first prototype magnets and the start of systematic magnetic measurements mark a major milestone.

Lessons learned from prototyping, together with ongoing refinements in magnetic, mechanical, and thermal design, are paving the way toward final designs and series production. Work during 2026 will focus on completing prototype validation, finalizing designs, and launching large-scale production to ensure timely readiness for the ALBA II upgrade.

ACKNOWLEDGEMENTS

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