Precision magnetic measurement: from CERN to industry and back

Magnets are key elements of the Large Hadron Collider (LHC), and the success of the LHC must in large part be attributed to the fabulous work of the CERN team that characterized these thousands of magnets. Since the tools for this exacting job were not available, most were developed at CERN. Continuing a symbiotic relationship that has endured more than 25 years, Metrolab Technology SA has licensed some of this technology, improving it and making it available to industry and other laboratories. The following is a brief retrospective.

NMR Precision Teslameters

In 1985, **Metrolab**'s first product was a high precision magnetometer based on the Nuclear Magnetic Resonance (NMR) effect – using a design licensed from CERN. Metrolab turned a delicate piece of scientific equipment, capable of measuring magnetic field strengths to within parts per million, into a tough industrialized instrument that could be operated by any technician. The chief beneficiary was the then-nascent industry for Magnetic Resonance Imaging (MRI), which has since become one of medicine's most important imaging modalities.

That NMR magnetometer went on to become the world's standard method for measuring strong fields to a very high degree of precision. Its direct successor, the Precision Teslameter PT2025, continues to be manufactured today (*see Figure 1*). It is only now that an all-new digital model, the PT2026, is preparing to replace CERN's original design. Its benefits include better resolution, greater measurement range, better performance in inhomogeneous fields, modern interfaces and much greater versatility.

Figure 1. *Metrolab's NMR Precision Teslameter PT2025, today's "gold standard" for magnetometry, originally based on a design licensed from CERN.*

Digital Integrators

The pattern repeated itself a few years later, when Metrolab licensed CERN's design for a Precision Digital Integrator (PDI). The PDI integrates the voltage of a moving coil, using Faraday's Law to compute the field strength at well-known positions, with a precision of roughly one part in 10^5. This very integrator, coupled with a sophisticated rotating-coil system, was used to characterize the LHC dipoles.

Metrolab industrialized this instrument by adding, for example, programmable-gain amplifiers and a flexible trigger facility. Thus was born Metrolab's Precision Digital Integrator PDI5025, which became the accepted standard at accelerator laboratories and magnet suppliers throughout the world – and remained so for over 20 years (*see Figure 2*).

Figure 2. *Metrolab's Precision Digital Integrator PDI5025, for decades the accepted standard for high-speed integrators, also based on a CERN design.*

In 2007, CERN presented a successor to the PDI, designed to work with a fast rotating-coil system. One of this system's primary objectives was to study transient effects observed in large superconducting magnets like the LHC dipoles. To match the fast rotating-coil system, the new Fast Digital Integrator (FDI) was designed to provide a 100x speed- and 100x resolution improvement over its predecessor.

Figure 3. *The Fast Digital Integrator FDI2056, replacement for the PDI5025, once again based on a CERN design.*

Once again, Metrolab decided to license this new CERN design, introducing it in 2010 as the Fast Digital Integrator FDI2056. Based on internal testing and customer feedback, Metrolab decided to undertake a number of improvements. Again, a major improvement was the flexible trigger facility, notably enabling the FDI2056 to accept all commonly available rotational and linear position encoders as trigger source.

Other low-level modifications include improved noise performance and linearity, synchronized acquisition on multiple channels, improved time resolution and trigger rate, and miscellaneous bug fixes. The most important improvement, however, is the transition from a board-level to a system-level product. The non-standard, low-level PCI interface has been replaced by a PDI5025 compatibility interface, as well as a "native" interface based on an Ethernet connection and industry-standard VXI-11, IEEE 488.2 and SCPI protocols (*see Figure 3*).

Two-way street

Metrolab has reaped tremendous benefits from its relationship with CERN, but so has the high-energy physics community. CERN itself has become an excellent customer of Metrolab's PT2025 – for example to calibrate the LHC rotating-coil systems – thus gaining access to a fully industrialized version of its own technology.

More generally, Metrolab has served to distribute CERN-developed technology to other accelerator laboratories. But rather than just distributing technology, Metrolab actually improves on it. Not to awaken latent rivalries between scientists and engineers, let us attribute these improvements primarily to a difference in perspective: CERN designs an instrument to respond to a specific need, whereas Metrolab aims to satisfy as broad a clientele as possible.

In fact, although the bulk of our product palette is no longer driven by high-energy physics applications, Metrolab has made a conscious effort to stay "plugged into" this community, for example by participating in conferences such as the Particle Accelerator Conferences (PAC, EPAC and IPAC) and the International Magnetic Measurement Workshop (IMMW).

The industrialization of CERN's magnetic measurement technology illustrates how the transfer of such specialized technology can, and should, work. Patent lawyers are not particularly useful: their cost is only amortized in large markets like smartphones. Incentives encouraging technology transfer are not particularly useful either: a durable symbiotic relationship should be incentive enough. What is useful is a platform to exchange ideas, similar to the IMMW conferences – plus a little bit of imagination.

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