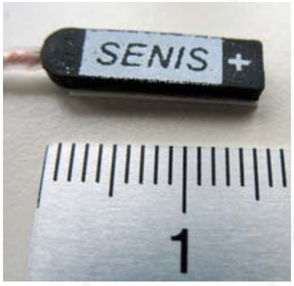
A New Generation of Hall Magnetometers: Enabling Technologies

The Hall effect was discovered in the 19th century, and Hall magnetometers are the most commonly used technique for measuring medium- to high-strength magnetic fields. Nonetheless, Hall magnetometers continue to evolve, offering new capabilities that benefit both industrial and scientific users.

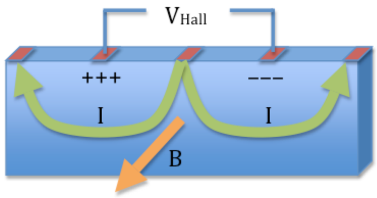
In this article we examine the technological developments underlying each of the components of a new magnetometer system: three-axis Hall sensor, electronics, PC software, and handheld option. These technological developments have enabled a major improvement in functionality as well as form factor and interfacing.

The sensor: a very big punch in a very small package



To measure the total field, we need three orthogonally oriented Hall sensors. Typically, three individual sensors are glued into a cube, roughly five to ten millimeters on a side. But now there is another way: a single IC containing one conventional planar Hall element and two sets of "vertical" Hall elements.

The vertical elements can be thought of as plates of N-type silicon inserted vertically into a P-type substrate. If a current is injected into the center terminal and extracted from the two end terminals, the currents in the two halves of the plate flow in opposite directions, resulting in a Hall voltage on the remaining terminals.



A team at the EPFL in Switzerland, led by Dr. Popovic, applied this technique to design a 3-axis sensor on an IC, called the MAG3D. The array of Hall elements measures 150 x 150 x 10 μm^3 – a million-fold reduction in active volume compared to a conventional approach! This allows precise position determination as well as consistent measurements of all three components even in highly inhomogeneous fields.

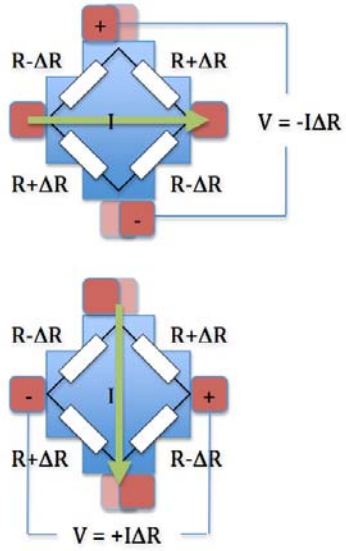
But MAG3D contains much more than the Hall elements. To build a Hall magnetometer, we need to supply a current and measure a voltage. By increasing the current and/or amplifying the voltage, one can increase the sensitivity. All this is done on the IC; the external electronics only supplies 5V power and two digital lines to select one of four ranges (.1, .5, 3 or 20 T). This represents a tremendous simplification of the magnetometer as a whole.

But there's more… All Hall magnetometers suffer from measurement offset – in other words, the instrument measures a non-zero result even in a zero field. What's more, this offset varies with time and temperature. One should calibrate the instrument in a zero-gauss chamber before each use, and the instrument has to continuously correct the measurement for temperature variations. Even so, offset remains a significant source of error.

110, chemin
du Pont-du-Centenaire
CH-1228 Plan-les-Ouates
Geneva, Switzerland

Téléphone +41 22 884 33 11
Fax +41 22 884 33 10
Web: http://www.metrolab.com
E-mail: contacts@metrolab.com

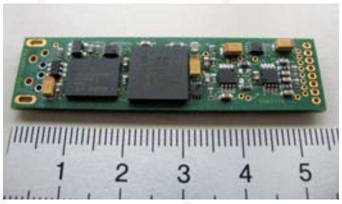
Banque Cantonale de Genève
CH-1211 Genève 2, Switzerland
IBAN CH86 0078 8001 R322 8381 3
SWIFT : BCGECHGG



Where does offset come from? One common source is misalignment of the terminals. As shown in the figure, the effect can be modeled with a resistance network, where the longer current paths result in higher resistances, and vice versa. In our example, the resulting offset voltage would be negative. But if we exchange the current and voltage leads, thereby functionally rotating the Hall element by 90°, the offset voltage becomes positive. It is important to note that the Hall voltage is unaffected by this rotation.

The MAG3D exploits this effect in two ways. The “spinning current” technique, where the voltage and current leads are rapidly switched back and forth and the results averaged, compensates for manufacturing imperfections such as terminal misalignment. In addition, by wiring orthogonally oriented pairs of sensors in series, the MAG3D increases its sensitivity while at the same time compensating for dynamic offset errors. This includes the planar Hall effect, whose magnitude changes sign when the current direction is rotated by 90°. The combination of these techniques results in a sensor with significantly reduced offset, offset drift, and sensitivity to planar Hall effect.

The electronics: also a small package, but with a different punch

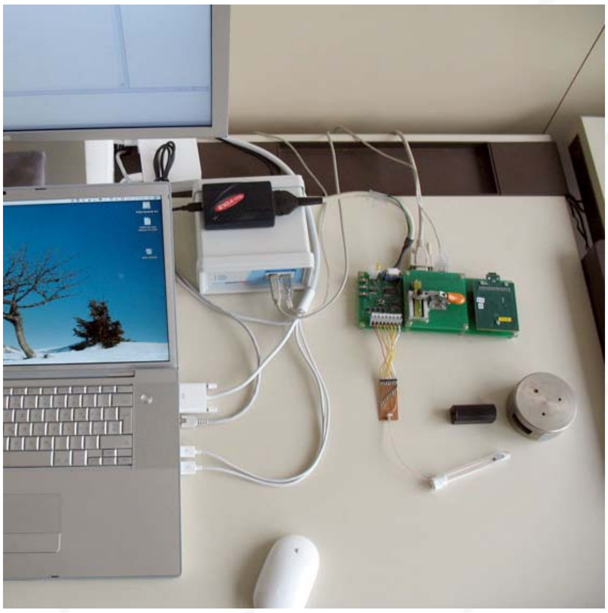


Unlike the sensor, the functionality of the electronics is hardly revolutionary: digitize the measurements; compensate for gain, offset and temperature variations; and output the result via USB. The innovation lies in the implementation.

The circuit board is only 14 x 55 mm^2, requiring an 8-layer PCB with highly integrated components on both sides. Such a circuit is challenging to design, even more challenging to debug, and simply impossible to prototype. Even purchasing the components is a challenge: often they are available only in large quantities, and sometimes they are obsolete even before the data sheet is finalized.

Moreover, a professional quality instrument consists not only of digital circuitry, but also includes a high-sensitivity analog front end and a high-stability power supply. The 5V power supplied by USB can actually drop to almost 4V, so a switching step-up supply is required to guarantee a stable voltage level. Getting this notoriously noisy circuit, plus the nearly equally noisy digital circuitry, to coexist with a high-sensitivity analog front end in the space of a few postage stamps is indeed a design challenge. The winner is the end-user, who now has a fully functional instrument shrunk to a fat spot in the cable.

As with most modern designs, most of the complexity is actually hidden in the firmware. Not too long ago, firmware was developed in assembly language and was therefore limited in complexity and tied to a particular processor. The development environment was supplied by the chip manufacturer or an embedded-tools specialist; in either case, it was expensive, bulky and very low-level. In the span of fifteen years, all this has changed dramatically. A complete development environment now plugs into a standard desktop computer, fits on the corner of a desk, and permits coding in high-level, object-oriented languages (usually C++). It has even become affordable.



So what has changed? One very important force has been the Open Source movement. The GNU C Compiler (gcc) and related tools are the high quality, state-of-the-art, multi-platform development suite that firmware developers could only dream of a few years ago.

The availability of these tools has also led to the development of high-quality operating systems and software libraries, often adapted from Linux or other Open Source projects. Although embedded-tools specialists still have their place, one can, with a little effort, assemble a development environment practically for free. Very importantly, if a library or system call is not working, the developer can look at the code to see whether he misunderstood the documentation or if it is broken. Most importantly, if the code really is broken (perhaps only on a particular platform), we can fix it – today.

Another important factor is standardization. Our new magnetometer conforms to the mechanical, electrical and protocol standards of USB; thus we ensure that it can be plugged into any PC and communicate on a basic level. Its conformance to the USB Test and Measurement Class (USBTMC) and USB488 Subclass standards allows it to plug and play with, for example, LabVIEW. It also conforms to the IEEE 488.2 and Standard Commands for Programmable Instruments (SCPI) standards, providing a leg up for programmers who might already be familiar with this command syntax. Finally, it conforms to the USB Device Firmware Upgrade (DFU) standard, thus helping ensure that this critical procedure completes without failure.

These standards ensure that the user can combine material from different vendors – but they also benefit the manufacturer. Standards represent a pool of experience and best practice. Standards also allow the development of reusable circuits, tools and code. For example, the USBTMC / IEEE 488.2 engine as well as the SCPI parser used in our magnetometer are third-party libraries. Standards obviously also have their downside – for example a steep learning curve and design constraints – but the benefits far outweigh the disadvantages.

PC software: LabVIEW as far as the eye can see

For a traditional instrument, software to interface it to a computer is nice to have; for an instrument without any knobs or buttons, it becomes an essential system component.

In our case, the required software is divided into four levels:

- USB Driver:
  Any USBTMC driver should work.
- Programming interface to communicate with an instrument:
  Again, there is a standard: the Virtual Instrument Software Architecture (VISA). Compliance with USBTMC and IEEE 488.2 further simplifies the job.
- Cross-platform programming interface to our instrument:
  The vast majority of our clients who write instrument control software use LabVIEW. We, too, supply our API in LabVIEW.
- Turnkey user interface:
  Users want to use their instrument out of the box, and most don't have LabVIEW. But we as manufacturer can use LabVIEW to create a stand-alone control program.

It turns out that LabVIEW is supplied with a USBTMC driver and VISA library. Thus all four levels are covered with a single software development environment that provides good compatibility, high quality, good support, and cross-platform capability. In this case, the benefits of a monolithic solution far outweigh the (monetary or psychological) costs. From its roots as a Mac-only graphical programming "toy," LabVIEW has grown up to be an enabling technology.

The portable option: PDAs and even more LabVIEW

From the start, we conceived our new magnetometer as a portable instrument – this is why we wanted it to be so small and power-efficient. The user interface in this case would be provided by a commercially available handheld computer, or Personal Digital Assistant (PDA). PDAs provide a high-resolution color touch screen, powerful processor, local storage and high-density battery, all in a compact and attractive package and for a price that we could never match.

But the choice of PDAs is much more restrictive than we expected. The PDA market is now shrinking, and even major manufacturers are abandoning it. In addition, the only major PDA operating system that supports a USB Host interface is Windows Mobile. And even amongst the Windows Mobile devices, most do not supply the USB Host hardware.

We also discovered that the product lifecycles of standard, consumer-grade PDAs are too short: an instrument manufacturer cannot afford to adapt his product every six to twelve months. Industrial-quality PDAs provide longer lifecycles, and are also designed to be more robust; however, they can be very expensive and often contain features we don't need: does a magnetometer really need WiFi, Bluetooth, GPS, a bar-code scanner and RFID reader? Finding the right PDA has turned out to be a lengthy process.

Finally, there is the issue of programming. We wanted to provide essentially the same capabilities and user interface in the portable instrument as on a PC. After a number of detours, we realized that LabVIEW once again provided the optimal solution. The LabVIEW PDA Module provides a USBTMC driver and VISA library for Windows Mobile, and it allows our API and UIF code to be ported from the PC with a minimum of effort. LabVIEW PDA Module turns out to be an enabling technology for us, with benefits that far outweigh the learning curve and licensing costs.

Evolution or revolution?

One can argue whether each of these developments is evolutionary or revolutionary. However, the cumulative effect is an instrument that looks nothing like a traditional gaussmeter: compact form factor, three-axis capability, small active volume, high field range, high sample rate, reduced offset and planar Hall effect, direct computer interface, programmability, handheld or bench-top use – the list of new capabilities is long and impressive. As with the desktop computer revolution, users are now challenged to rethink how they can best use these new tools.