What are magneto-inductive MEMS?

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I recently missed a meeting at the University of Arizona in Tucson because their parking lot was full and, not being familiar with the area, I drove around looking for an empty parking space until it was too late to keep my commitment and I had to call to re-schedule the meeting. Driving around looking for a place to park your car is a ‘hit-and-miss’ endeavor that adds lots of unnecessary CO$_2$ to our environment (Europeans are especially conscious of this). How would you like to have a device in your car that can locate available parking spaces in the area and guide you right to it?

The above example is only one situation and need for an application using a magneto-inductive (MI) sensor in its design. There exists a myriad of other possibilities for this type of sensor, only limited by the designer’s imagination. Let’s first look at what the MI is and how it works, then we can discuss an example of one possible use for getting you a parking spot.

The magneto-inductive sensor

PNI Corp. has an MI sensor IC, the MS2100, consisting of two MI sensors making up a two-axis sensing solution plus a control ASIC. We will use this sensor as an example in the following tutorial. The following is how an MI sensor works and what sets the PNI solution apart from anything else out there that I have seen in performance.

There are many ways to employ an MI sensor but the usual circuit includes an L/R oscillator configuration with the MI in the feedback of a Schmitt trigger (Figure 1).
Figure 1 A typical MI sensing circuit design (Image courtesy of PNI)

The magnetic field parallel to the coil is shown as $H_E$. $H$ is the total magnetic field that the MI sees and is a function of two elements: the magnetic field formed by the current, $I$, in the circuit and the external magnetic field. See **Equation 1** in which $k_0$ is a constant depending upon the physical parameters of the particular sensor.

$$H = k_0 I + H_E \quad \textbf{Equation 1}$$

For **Figure 1**, it is assumed that there is a “0” value at the Schmitt trigger input, A; i.e., 0 or some value less than the trigger value. The output then inverts to a logic “1” at a voltage we will call $V_s$. Now that $V_s$ across the voltage up across the MI sensor until the point A voltage reaches the Schmitt trigger threshold voltage, $V_H$, and is seen as a logic “1” at Point A, thereby making the output a logic “0”. Now the voltage across the MI sensor is driven down and the result is a sustained oscillation (Figure 2).

Figure 2 The waveforms for the oscillator circuit. The current, $I$, follows the voltage waveform at point A. (Image courtesy of PNI)
Now here is the underlying principle to PNI’s magneto-inductive sensing technology. PNI designs its MI sensors with a solenoidal geometry coil which gets wrapped around a high-permeability magnetic core. The inductance of such a highly permeable material varies with the applied magnetic field. So the sensor’s inductance, $\mu$, is a function of $H$, the magnetic field (Figure 3).

![Figure 3](image.png)

**Figure 3** The graph shows the inductance, $\mu$, of the highly permeable material vs. $H$, the magnetic field. (Image courtesy of PNI)

In Figure 1, $R_b$ is the bias resistance and it, along with the voltage $V_s$ on the Schmitt trigger, are chosen so that the sensor’s magnetic field is in the non-linear region of the permeability curve shown in Figure 3.

Now let’s look at the voltage output when this circuit is driven with a positive or a negative bias without an applied external magnetic field (Figure 4).
Now we apply an external magnetic field, $H_e$ which can also be the Earth’s magnetic field, and we see that both the positively and negatively biased curves shift in the same direction. It can be seen that when the circuit is positively biased, the shift causes the inductance to increase and when it is negatively biased, the inductance now decreases. This effect causes $\tau$, the period between cycles, to increase for the positively biased circuit and decrease for the negatively biased (Figure 5).
Figure 5 The sensor circuit operation with an applied external magnetic field is shown here. (Image courtesy of PNI)

Now, if we measure the time to complete a fixed number of oscillations or periods which occur during the forward and reverse polarity directions, then take the difference between these two values, we can derive the strength of that external magnetic field.

Smart parking: PNI’s PlacePod cloud architecture

Although there are existing products out there in the industry, accurate and timely vehicle detection is lacking. Enter the PNI PlacePod, an IoT-enabled, smart parking sensor that facilitates on- or off-street parking in either a private or municipal parking management facility. PNI claims that it is the industry’s most accurate magnetic sensor system for vehicle detection. The system combines PNI’s 3-axis RM3100 geomagnetic sensor and the SENtral-A2 coprocessor with algorithms for accurately detecting the presence or absence of a vehicle in a particular parking space (The device has two states: empty and vehicle parked) (Figure 6).
Figure 6 PlacePod offers end-to-end encryption, multiple nodes, easy installation, and integrates with third-party networks. (Image courtesy of PNI)

A major reason PNI’s design stands out among the rest of the field is that these sensors and mature algorithms are designed for ultra-low power consumption and are continuously in an on state, as opposed to other systems which go into a sleep mode to conserve power—this is the time when you can miss that a vehicle has either come or gone from the parking space. I find this and the following reasoning to be a very compelling reason for designers to select this solution over others in the market from what I see out there in the industry today.

Some other features that set this device apart are:

- Stability over temperature is critical, especially in varying outdoor temperatures. Temperature stability is inherent to the device because of the reverse forward-biasing nature of PNI’s MI circuit which athermalizes (i.e., becomes independent of temperature or thermal effects) the output since the changes in the bias resistance or the inductance over temperature are experienced in both the forward and reverse directions and hence are cancelled.
- The device has essentially a digital output which produces a clearly defined value directly related to the applied magnetic field. Many other devices have an analog output which would need the addition of an op amp and A to D converter externally.
- The device is capable of a high resolution of 10 nT using the basic circuit. Other devices have a noise floor which limits their resolution, or are more costly in order to get better resolution using external components.
- The device’s low power consumption, due to the MI technology, is inversely proportional to the sample rate. With an 8 Hz sample rate, power consumption is typically 1.5 mW; at a 300 Hz sample rate, it is 7.5 mW. A magneto-resistive sensor (MR) solution will typically consume 15 to 30 mW. A 10 year battery life is possible depending upon the configuration and distance of the device from the gateway.
- This device has no need for reset like an MR technology which often needs a high current pulse to be sent through that sensor in order to reset the magnetic domains within the core material. This reset pulse also generates a large peak power of several watts which may cause problems in other devices in the system.
- There is no hysteresis to affect accuracy in the MI sensor due to the forward reverse bias nature of the MI circuit.
The system uses Bluetooth Low Energy (BLE) for simplicity of the wireless set up and calibration, as well as providing diagnostics and software updates using a mobile or a desktop app. It is IoT-enabled with LoRaWAN 1.0 compliant compatibility using the built-in, long-range 915 MHz LoRa-based radio module for communication (uses sub-GHz ISM bands in North America and Europe) with a LoRa-enabled gateway.

The device can be either embedded into the ground or inserted onto the surface of a street, road, or into parking spaces in multi-level/single-level parking structures since it has a robust polycarbonate housing (Figure 7).

Finally, the device is environmentally tested to MIL-STD-810G and NMEA Type 4 IP67 (IEC60529). Please provide your comments and experiences regarding this technology and solution with our audience for discussion below in our comments section.

References

1. Magneto-Inductive Technology Overview, Andrew Leuzinger and Andrew Taylor, PNI Corp., February 2010
Also see:

- Motion sensors de-mystified
- What if you couldn't parallel park your car?