GEM Systems
ADVANCED MAGNETOMETERS

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Short Review of Optically Pumped Scalar Magnetometers

Magnetometers can be divided into two categories that vary dramatically both in terms of functionality and principle of operation. Vector magnetometers measure the magnetic flux density value in a specific direction in 3-dimensional space whereas scalar magnetometers measure only the magnitude of the vector passing through the sensor regardless of the direction.

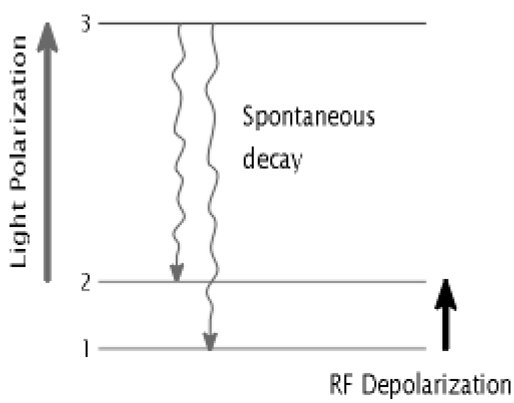
GEM delivers both vector (observatory models) and scalar magnetometers, but we limit this discussion to scalar magnetometers and specifically optically pumped varieties, which differ from their nuclear counterparts as discussed in other GEM scientific and technical papers.

Optically Pumped Magnetometers

Optically pumped magnetometers use alkali metals from the first column of the periodic table such as cesium and potassium, and they all operate on virtually the same principle.

First, a cell containing the gaseous metal is polarized (or pumped) by exposure to light of a very specific wavelength. The light depopulates one electron energy level in the gas by pumping the electrons to a higher energy level. These electrons spontaneously decay to both energy levels, and eventually, a lower energy level is fully populated.

Next, the cell is “depolarized” by shifting the electrons in the lower energy level back to their original position using lower wavelength RF power.



The energy required to repopulate this energy level varies with the ambient magnetic field, according a principle called the *Zeeman* effect. Therefore, the frequency of the depolarizing RF power corresponds to the magnetic field value. The Zeeman effect is not a unique energy

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difference in an alkali metal, however. All alkali metals possess several different Zeeman effect energy levels, each of which is proportional to magnetic field. These discrete energy levels are called *spectral lines.*

Because of the physics of the system, the intensity of the Zeeman effect is dependent on the direction of the ambient magnetic field with respect to the direction of applied light and RF power. This creates 'dead-zones' around the magnetometer sensor, which manifest as a loss of signal when the sensor is improperly oriented in the ambient field. The tolerance of this orientation is high, however - usually between 10 to 80 degrees of sensor orientation.

In addition, these magnetometers require the alkali metal to be gaseous to operate. That means that the cell containing the metal must be continuously heated to approximately 45° C.

Potassium

The potassium atom's spectral lines are extremely narrow and they do not overlap. As a result, the design of a potassium magnetometer is more complex than that of a cesium magnetometer that tracks much broader spectra. (Historically, manufacturers have focused on cesium for this reason but GEM is proud that its potassium development efforts have led to the world's only commercial potassium magnetometers.)

The fact that potassium's spectral lines do not overlap means that utilizing potassium will result in a magnetometer sensor with very low heading error. It also means that a potassium magnetometer never requires calibration. The only component that wears out is the light source (the potassium lamp), which has a lifetime of thousands of hours, and is economical to replace.

Another benefit of narrow spectral lines is potassium's huge bandwidth and superb sensitivity. In the laboratory, special potassium magnetometers have shown noise levels of less than 0.05 pT, and have tracked varying magnetic fields as high as 10,000 nT/sec. GEM Systems has developed a new potassium magnetometer that will take advantage of these benefits.

Cesium

The Cesium alkali vapour magnetometer offers reasonable sensitivity and bandwidth (a few pT at 10Hz sampling) but has a few disadvantages that make it an expensive instrument to own and operate.

Cesium's spectral lines are quite wide, meaning that the electron energy levels associated with the Zeeman effect vary widely in magnitude over a population of Cesium atoms. Cesium's spectral lines are very wide and very strong; as a result, the spectra overlap, making it impossible to distinguish conclusively between them.

In static conditions, a peak becomes apparent, and the system will self-oscillate at this peak. When the magnetic field direction changes, however, the position of this peak changes because the spectral line amplitudes change.

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As a result, the self-oscillating frequency will shift, producing a *heading error.* Since Cesium's spectral lines are spread over more than 20nT, the heading error could be that severe. Split-beam techniques attempt to stabilize the lump over different magnetic field directions, but still cannot achieve better than about ±1nT.

Because of this characteristic, the performance of a Cesium magnetometer depends heavily on the orientation of the applied light power with respect to the applied RF power. Small mechanical shifts within the sensor can cause large numerical shifts in the instrument's output. For this reason, a Cesium magnetometer must return to the factory periodically for re-alignment of the sensor. The cost of this realignment can be significant.