

**Magnetic FX**

Processing Magnetometer Signals

White Paper

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**Magnetic FX**

**Introduction**

Geophysicists face the challenge of conducting non-invasive exploration of subterranean locations. These activities include mining exploration, discovering underground water sources and detecting unexploded ordnance by measuring changes to the frequency of the earth’s local magnetic field using a caesium vapour magnetometer. A disturbance in the magnetic field may indicate the presence of a feature of interest beneath the ground. Due to unknown depth and size of any subterranean feature, the accuracy of the detected change in magnetic field is important.

Caesium Vapour Magnetometer Sensors (such as Geometrics G822A) are of great interest in geophysics for mapping the terrestrial magnetic flux density (the 'field'). The output of the sensor is a sinewave voltage where the frequency is proportional to the field. The problem of acquiring the field measurement comes down to measuring the frequency of the sensor's electrical output. Processing the signal needs to be real-time, specifically, with a delay that the operator barely notices, i.e., 0.5 seconds. Conventional frequency counting methods involve a trade-off between the measurement rate and the rounding error.

We are interested in exploring an option that will ensure the precision of the frequency reading from a caesium vapour magnetometer is as accurate as possible.

**Background**

There are a wide assortment of magnetometers that measure various characteristics of magnetic fields for a variety of applications. A very commonly known version of a magnetometer is a compass which has a magnetised swinging arm that measure the direction of the Earth’s ambient magnetic field. The caesium vapour magnetometer, which is of interest to us, is a scalar magnetometer and measures the strength of a magnetic field at any particular location. In simple terms it does this by exciting caesium atoms within the instrument into higher states, which is then primed ready for measurement.

**Magnetic FX**

As outlined in Wikipedia (n.d.):

“When an external field is applied it disrupts this state and causes atoms to move to different states which makes the vapour less transparent. The photo detector can measure this change and therefore measure the magnitude of the magnetic field.”

When a very small AC magnetic field is applied…there is a frequency at which the field makes the electrons change states. In this new state, the electrons once again can absorb a photon of light. This causes a signal on a photo detector that measures the light passing through the cell. A signal is generated exactly at the frequency that corresponds to the external field.

Approximately one million frequency readings can be taken in one second. However, when calculating the frequency of a wave, it is common practice to count the number of complete waves, or pulses, in a particular amount of time. If there are not an exact number of waves, the remainder portion of the wave is discarded, or rounded to the closest number of waves, which may cause rounding errors to enter into the frequency calculations. This will ultimately alter the precision in the detection of a change in the magnetic field at a particular location. The problem being considered by the Magnetic FX Group is whether there is a more precise measurement of frequency that will eliminate such rounding errors and increase accuracy in subterranean object detection.

**Proposed solution**

In conjunction with our industry partner, Mr Ron Bradbury, Magnetic FX proposes that a solution to this problem would be to utilise the Hilbert transform in a more accurate calculation of frequency in the output of a caesium vapour magnetometer. The Hilbert transform is a function which has mostly been applied to signal processing. It is useful for determining the analytic signal. To facilitate a more accurate calculation of frequency, the toolbox function Hilbert in MATLAB was used to calculate the Hilbert transform for data (x). It returns a complex result of the same length, y = hilbert(x).

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The real part of y is the original data, and the imaginary part is the actual Hilbert transform. y is often referred to as the analytic signal, in reference to the continuous-time analytic signal. One of the properties of the discrete-time analytic signal is that its Z-transform is 0 on the lower half of the unit circle.

The algorithm also calculates the (complex) discrete analytic signal and the argument of the analytic signal (the signal phase). It then differentiates the phase (the signal frequency) and computes the magnetic field.

To render this software useful for field work, consideration must also be made in regards to processors and architecture to integrate and embed the program into a mobile digital signal processing system with a user interface, however is outside the scope of this paper.

**Conclusion**

Using the Hilbert transform in the calculation of frequency is a significant improvement and important upgrade to a Caesium Vapour Magnetometer Sensor, particularly where data can be outputted in real time within a mobile device. The Hilbert transform will provide more precise readings and thus allow for timely and accurate detection of subterranean features in the field.



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**References**

Magnetometer. (n.d.). In Wikipedia. Retrieved September 28, 2022 from <https://en.wikipedia.org/wiki/Magnetometer#Caesium_vapour_magnetometer>

Than, K., (2014) Electrons in magnetic field reveal surprises [Image]. Retrieved from

<https://physicsworld.com/a/electrons-in-magnetic-field-reveal-surprises/>