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Enabling Vector Magnetic Field Measurements in a Single-Axis Optically Pumped Magnetometer

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Optically Pumped Magnetometers (OPM) have been a promising technology for magnetometry. Zero-field OPMs have evidenced a capability to measure magnetic fields as small as 10 fT [1] with sensitivity levels ranging from 1 fT/√Hz [2]. Moreover, the practical advantages of the OPM include its compact size and independence of the cryogenic environment, unlike SQUID-based magnetometers [3]. These specifications make the OPM one of the most sought-out technologies for quantum magnetometry [4]. In fact, OPM fits well for biomedical applications such as magnetoencephalography as well, because of its flexibility to fix all subject sizes [5].

Traditionally used OPMs were built as single-axis magnetometers. The single-axis magnetometer measures one of the components of the magnetic field aligned with the direction of the sensor. If the sensor is misaligned with the direction of the magnetic field, it misses some of the information, such as the fields tangential to the sensor. Moreover, the tangential fields introduce measurement errors along the axis. To address this, the triaxial magnetometer [6], which measures the full vector magnetic field, is considered a better alternative. However, apart from the merits, there exist a few non-ignorable points, such as this complex setup requires a beam splitter which halves the power of the laser and increases the noise floor [7]. This noise floor surpasses the noise floor of the single-axis magnetometer [8]. Furthermore, the single-axis magnetometer is cost-effective and compact compared to the triaxial magnetometer.

This theoretical work proposes a novel approach to measure the total magnetic field using a single-axis magnetometer rather than a triaxial magnetometer. While single-axis OPM measurements are generally performed by analysing the principal frequency component of the polarisation signal, we show that the higher-order frequency components contain information on magnetic field components transverse to the measurement axis. Through the development of an accurate OPM model, we characterise this additional information and propose a novel post-processing technique allowing the extraction of the full vector magnetic field in a single-axis measurement.

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