Low-Cost Portable ELF and DC Magnetic Field Meter Based on TMR and Inductive Sensors

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***Abstract*—This work presents a low-cost portable system for three-axis measurement of extremely low-frequency (ELF) and static magnetic fields using MC858 and MC95A inductive sensors and CT220 tunnel magnetoresistance (TMR) sensors. The system integrates dedicated analog signal conditioning, 16-bit digital acquisition, Bluetooth communication, and battery-powered operation. Experimental characterization was performed using Helmholtz coils at magnetic flux densities up to 200 µT and frequencies of 50, 100, and 150 Hz, with the generated field independently verified using a commercial EMF-8218SD meter. The MC858 showed good performance around the 50/60 Hz power-line frequency but reduced sensitivity at higher frequencies, whereas the MC95A provided the most stable broadband response. The CT220 enabled both AC and DC measurements, demonstrating the flexibility of the proposed system for environmental monitoring, laboratory measurements, and electromagnetic compatibility applications.**

Keywords—extremely low-frequency magnetic field, static magnetic field, magnetic field measurement, inductive sensor, tunnel magnetoresistance sensor

I. Introduction

Extremely low-frequency electromagnetic fields (ELF-EMFs) are common in residential, occupational, and industrial environments, with major sources including electrical appliances, power distribution systems, transformers, and high-voltage power lines. Magnetic fields are typically dominated by the 50/60 Hz power-line frequency [1]–[3], and their reliable characterization is relevant to exposure assessment and electromagnetic compatibility studies [1], [3]. Reliable characterization of ELF magnetic fields is important for exposure assessment and comparison with established exposure guidelines [1], [3], [4]. ELF magnetic fields are also relevant to active implantable medical devices, particularly cardiac pacemakers, where electromagnetic interference may affect sensing or stimulation functions [5]–[7].

Recent portable magnetic-field measurement systems have employed Hall-effect sensors [8], MC858 inductive sensors [9], induction coils [10], fluxgate sensors [11], and magnetoresistive technologies including TMR [12]. However, these systems generally target a specific sensing principle or measurement scenario, limiting their flexibility for combined static and time-varying magnetic-field measurements.

This work presents a low-cost modular three-axis magnetic-field measurement system combining MC858 and MC95A inductive sensors for ELF measurements with CT220 TMR sensors for both static and time-varying magnetic fields. Dedicated AC and DC signal-conditioning paths, 1 kHz digital acquisition, Bluetooth communication, and battery-powered operation provide a flexible platform for portable measurements. The system was experimentally evaluated using Helmholtz coils inside a Faraday cage, with a commercial EMF-8218SD magnetic field meter used as a reference to verify the generated magnetic-field levels.

II. Design of ELF and DC Magnetic Field Meter

The acquisition board was designed as a modular analog front-end for three-axis static and ELF magnetic-field measurements, combining interchangeable sensors, dedicated signal conditioning, high-resolution analog-to-digital conversion, wireless communication, and battery-powered operation.

A. Input Stage

For ELF measurements, three orthogonally arranged MC858 [13] or MC95A [14] inductive sensors (Magnetic Sciences Inc., USA) provide simultaneous measurement of the X-, Y-, and Z-components. The MC858, with a sensitivity of 22 mV/µT, is optimized for 10–400 Hz with maximum sensitivity near 58 Hz, making it suitable for 50/60 Hz measurements. The MC95A, with a sensitivity of 10 mV/µT, extends the operating bandwidth to 10 Hz–10 kHz with a nearly flat frequency response, enabling measurement of higher-order harmonics and broadband electromagnetic interference.

Alternatively, three orthogonally mounted CT220 [15] tunnel magnetoresistance (TMR) sensors (Crocus Technology, USA), with a sensitivity of 1.5 mV/µT, are used for static and low-frequency magnetic fields. Unlike inductive sensors, which respond only to changing fields, the CT220 directly measures magnetic flux density and therefore enables both DC and low-frequency AC measurements, as shown in Fig. 1.

B. Signal Conditioning and Data Acquisition

Each sensor output is buffered by a MAX4163 voltage follower to provide high input impedance and minimize sensor loading. Signals from the MC858 and MC95A sensors pass through an active band-pass filter of approximately 10–340 Hz, suppressing DC drift and high-frequency noise while preserving the 50/60 Hz component and its harmonics. For CT220 DC measurements, a low-pass filter with a cutoff