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A real time high sensitivity high spatial resolution quantum well hall effect magnetovision camera

Chen-Wei Liang, Ertan Balaban, Ehsan Ahmad, Zhichao Zhang, James Sexton, Mohamed Missous*

School of Electrical and Electronic Engineering, The University of Manchester, Sackville Street, Manchester M13 9Pl, UK

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ABSTRACT

A real time magnetovision camera with a refresh rate of 600 frames per second (fps) was developed based on small size, high sensitivity Quantum Well Hall Effect (QWHE) sensors. This handheld system consists of a 16 × 16 QWHE sensor array covering an 80 mm × 80 mm area. This system has a spatial resolution of 5.08 pixels per inch (ppi). By using a superheterodyne technique to reduce the impact of (1/*f*) noise, magnetic fields down to 2 μT can be detected for both direct and alternating magnetic field operations. Experimental results of five case studies demonstrate that magnetic flux leakage (MFL) and magnetovision imaging in DC and AC magnetic field resulting from defects and shape, can be successfully measured. The major applications of this new system are: (1) in MFL testing equipment with permanent magnets or electromagnets, (2) to obtain 2D graphical imaging similar to magnetic particle inspection (MPI) without its inherent drawbacks, (3) for examination of non-ferromagnetic materials such as aluminium, copper, and stainless steels for deep defects below the surface using low frequency alternating magnetic fields, and (4) for material identification, which has a considerable potential in several applications such as in security, product protection, bio-imaging, and medical.

1. Introduction

The method of magnetic imaging is a useful technique to determine the distribution of magnetic fields where they reflect the conditions of a material. Turnanski and Stabrowski [1] used a giant magnetoresistive (GMR) probe with eight Permalloy sensors to analyse the magnetic field distributions at the surface of electrical steel sheets. The results were presented in the form of a contour map on a visual display unit. Lo et al. [2] developed a magnetic imaging system for non-destructive evaluation of structural and mechanical conditions. This system used magnetic hysteresis and Barkhausen effect to measure the magnetic properties. When scanning through the surface of a material, the measured data are converted into an image to show variations in the material conditions from one location to another. Tumanski and Baranowski [3] designed an anisotropic magnetoresistance (AMR) sensor array for investigation of the magnetic field distribution during testing of electrical steel strip magnetised by a magnetising winding.

A magnetovision system can directly display magnetic field distributions in the form of colour maps without converting the data into an image [4]. Baudouin et al. [5] used a magnetovision method to test non-oriented steels after tensile deformation. Other applications of this system are in non-destructive testing (NDT) of materials or in the experimental determination of magnetic field distribution. Tumanskiy and Stabrowski [6] used a magnetovision system to provide a versatile tool for non-destructive quality control and for the determination of the structural uniformity of electrical steel. Tumanski and Liszka [7] demonstrated a magnetovision system using a linear eight-sensor array module, robotic scanning mechanisms and a software numerical method for image reconstruction. Nowicki and Szewczyk [8] designed and built an XY scanning system with a tri-axial magnetoresistive sensor (Honeywell HMR2300) for detection of contraband ferromagnetic objects. Their system's ability for passive detection of hidden or buried contraband objects and the determination of their location was demonstrated.

Magnetic sensor arrays are very convenient for rapid magnetic imaging. However, in comparison with light sensors, magnetic sensor arrays are still rarely used [3]. The most commonly used magnetic field sensors in NDT are induction coils, magnetodiodes, fluxgates, GMR, AMR and Hall Effect sensors. Since different NDT

* Corresponding author.
E-mail address: m.missous@manchester.ac.uk (M. Missous).

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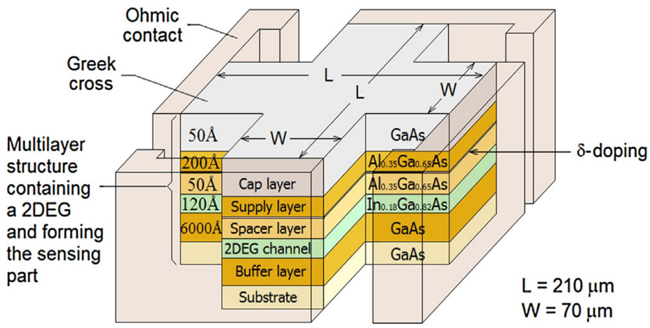

Fig. 1. Schematic illustration of 2DEG Hall Effect sensor showing the quantum well channel.

methods rely on different type of magnetic field sensors, the detection limits are set by the limitations of each particular sensor. Among all the magnetic field sensors, Quantum Well Hall Effect (QWHE) sensors fulfil the requirements of high magnetic sensitivity and reliability, low power consumption and small dimensions, large signal-to-noise ratios and low temperature dependence, together with reduced process and cost [9,10]. Therefore, the use of Hall Effect sensors have been increased in the fields of automation, medical treatment and detection [11,12].

In this work, a prototype handheld magnetic field camera has been developed (size: 400 mm × 225 mm × 42 mm) using 16 × 16 QWHE sensor array. The QWHE sensors, denoted as P2A, use AlGaAs/InGaAs/GaAs materials and are particularly optimised for the measurements of low magnetic fields (nano Tesla). The spatial resolution of the system is 5.08 ppi. This actual resolution has been enhanced to 40.6 ppi using a bilinear interpolation method [13], the details of which can be found in "Supplementary data". By using a superheterodyne technique, magnetic fields down to 2 μT can be detected for both alternating and static magnetic field operations. The system can be used in multiple sampling measurements enhancing the signal to noise ratios and for use in real time measurements for fast scan speed requirements.

2. Experimental

2.1. Fabrication of QWHE sensors

Currently, commercial Hall Effect sensors are mostly fabricated on traditional silicon-based technology, which has limited sensitivity but benefits from very sophisticated integrated electronics. The main difference between the GaAs QWHE and conventional Si CMOS field-effect transistors is the high mobility Quantum Well (QW) channel. This is a thin layer of a narrow band-gap semiconductor sandwiched between two larger band-gap materials. All

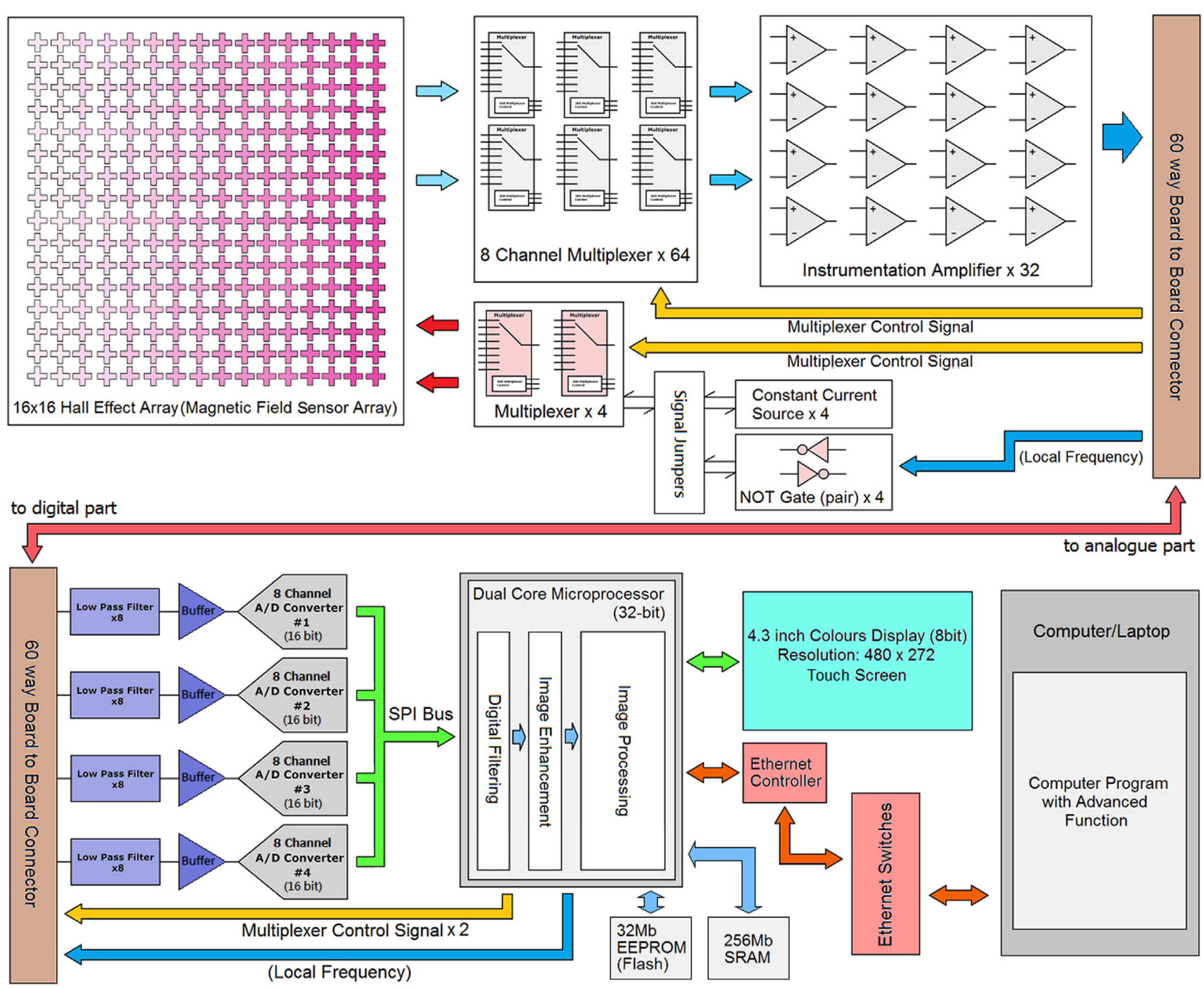

Fig. 2. Circuit block diagram of the 16 × 16 QWHE array magnetometer.