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Characterization and Comparative Evaluation of Novel Planar Electromagnetic Sensors

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The characterization of three types of novel planar electromagnetic sensors: 1) meander; 2) mesh; and 3) interdigital configuration, has been studied and their comparative performance has been evaluated based on their areas of applications. All of them are suitable for inspection and evaluation of system properties without destroying them. The experiments on fabricated sensors have been conducted and the results are presented here. The target application is to use a mixture of different types of sensors to detect plastic landmines.

***Index Terms*—Meander, mesh and interdigital type, nondestructive evaluation, planar electromagnetic sensors, plastic landmine detection.**

I. INTRODUCTION

NONDESTRUCTIVE evaluation techniques are able to detect the presence of cracks, discontinuities, mechanical fatigue, and many other imperfections without material damage. As a result, the application of this technique has increased considerably in recent times. It has been demonstrated that mechanical stress has the ability to change the electrical properties [1]. So the change of electrical property, such as electrical conductivity, can be used as an index of mechanical fatigue. The planar meander-type magnetic sensor has been used for the inspection of defects in printed circuits [2]. The characterization of a planar-type mesh sensor has been reported [3], [4], which can be used in many areas and can overcome the directional problem of meander type. The sensitivity of meander- and mesh-type sensors to dielectric materials can be overcome by another planar sensor of interdigital configuration. A controlled frequency excitation system has been developed and fabricated to supply the excitation of the sensors. The characterization and comparative performance evaluation of all the sensors have been carried out. A mixture of different types of sensors can be used together for novel applications, one of which is plastic landmine detection.

II. RESEARCH WORKS EMPLOYING PLANAR-TYPE SENSORS

Research works employing planar meander-type sensors, as shown in Fig. 1, started quite a few years back with the target of development a complete inspection system of the printed circuit board (pcb) of a Pentium processor [2]. The exciting coil is of meander configuration whereas the sensing coil is of either mesh-type or figure-of-eight-type configuration. The pcb of a Pentium processor, as shown in Fig. 2, having many long conductors, the meander-configured exciting coil is a suitable choice. The effective area of a meander sensor is given by the product of width and length as shown in Fig. 1.

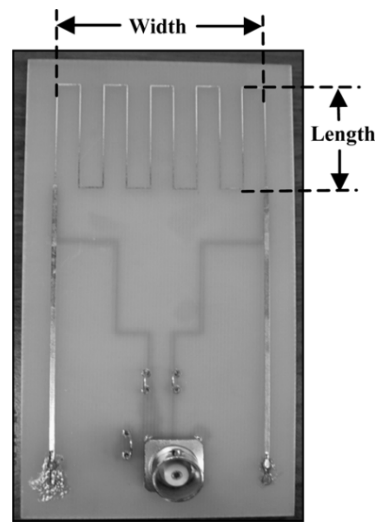

Fig. 1. Fabricated meander-type planar electromagnetic sensor.

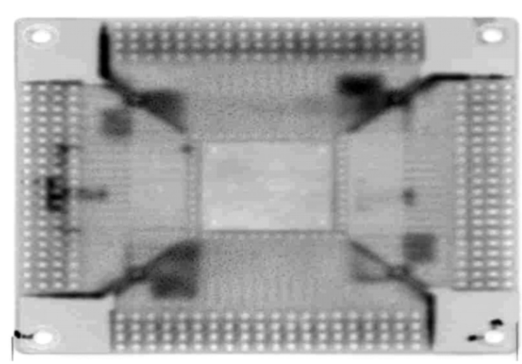

Fig. 2. PCB of a Pentium processor.

The planar meander-type sensor has also been used for the inspection of material defects such as the existence of inner layer cracks and for the estimation of fatigue of metal products [5]. A crack with alignment in parallel with the exciting meander coil is difficult to be detected by meander configuration. The alternative is to employ mesh-type sensors as shown in Fig. 3(a) [3], [4]. The response of both meander- and mesh-type planar electromagnetic sensors to dielectric materials is moderate. In order to increase the sensitivity of the sensor system, another type of sensor, the interdigital one as shown in Fig. 3(b), has been fabricated and developed. The effective areas are shown by dashed

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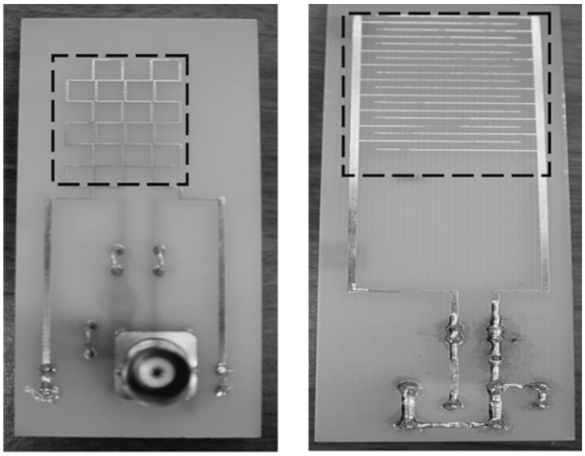

(a) mesh type (b) interdigital type

Fig. 3. Fabricated planar electromagnetic sensor: (a) mesh type and (b) interdigital type.

Fig. 4. Magnetic flux lines for meander sensor obtained from the FE model.

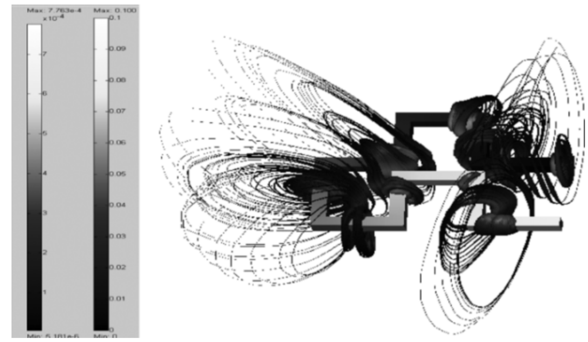

Fig. 5. Magnetic flux lines for mesh sensor obtained from the FE model.

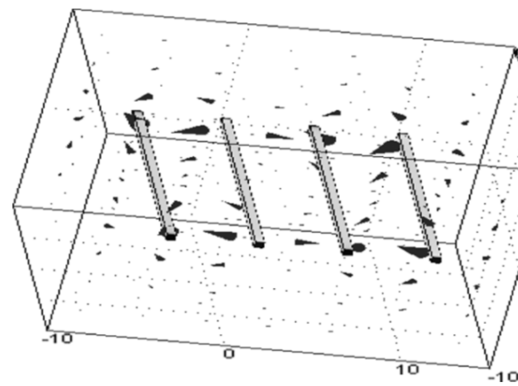

Fig. 6. Electric flux lines for interdigital sensor obtained from the FE model.

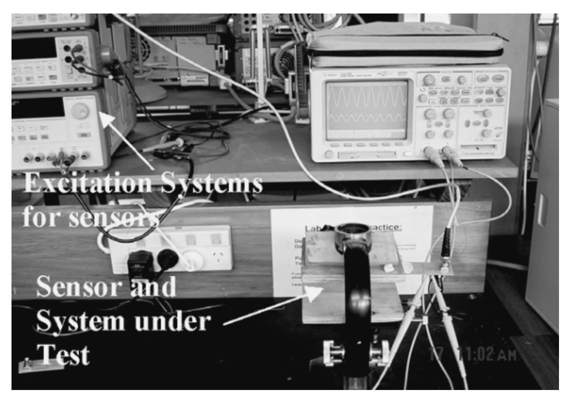

Fig. 7. Experimental setup for sensor characterization.

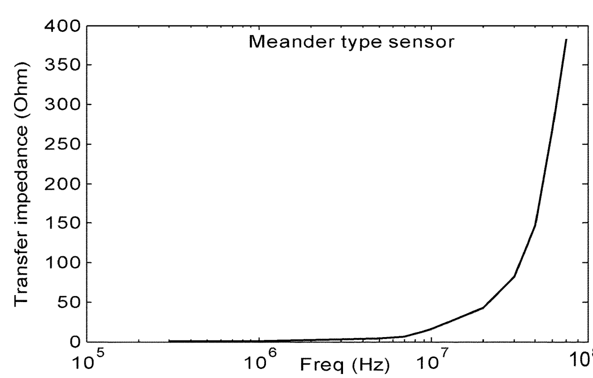

Fig. 8. Transfer impedance characteristics of meander-type sensor.

boxes. Experiments have been conducted on all sensors and the results are reported.

III. Characterization of Planar Sensors

Both meander- and mesh-type sensors consist of two coils: one used for excitation and another for sensing. The high-frequency alternating supply is provided to the exciting coil and the voltage across the sensing coil is measured. Transfer impedance (the ratio of the sensing voltage to the exciting current) is used as the characterization parameter for meander- and mesh-type sensors. In case of an interdigital sensor, the exciting voltage and the displacement current through the sensor are measured. Impedance (the ratio of the applied voltage to the current) is the characterization parameter used for the interdigital sensor. The sensors are modeled using the finite-element method. The finite-element software package FEMLAB has been used for modeling. To avoid a large memory requirement and a long computation time, only one pitch of each sensor has been modeled. Figs. 4 and 5 show the magnetic flux lines that are dominant for meander- and mesh-type sensors. Fig. 6 shows the electric field lines that are dominant for the interdigital sensor. Since the end target is to make a sensing system, the measured characteristics will provide more insight toward the development. The experimental setup is shown in Fig. 7.

Different sizes of sensors of meander, mesh, and interdigital types have been experimented using the experimental setup. The sensor has been supplied from a high-frequency supply, and the voltage across and the current through the sensor are recorded. The frequency of excitation has been varied between 100 kHz and 100 MHz. The impedance characteristics of the sensors are shown in Figs. 8–10, respectively. It is seen that the

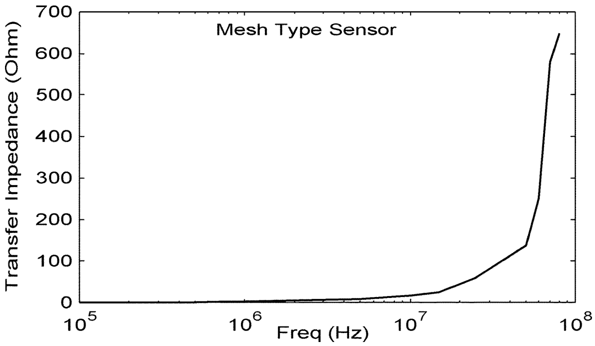

Fig. 9. Transfer impedance characteristics of mesh-type sensor.

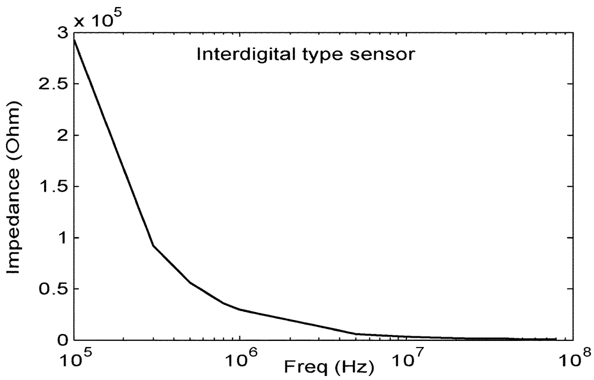

Fig. 10. Transfer impedance characteristics of interdigital-type sensor.

transfer impedance for both meander and mesh types increases with the increase in frequency whereas the impedance of an interdigital-type sensor decreases with frequency. With the same effective area, the response of mesh-type sensors is better than the meander type. Basically, meander- and mesh-type sensors are inductive types whereas the interdigital one is a capacitive type. It is also seen that both meander- and mesh-type sensors response well at high frequency, whereas the response of the interdigital sensor is very good at low frequency and does not response well at high frequency. The selection of operating frequency is to be carefully selected.

IV. Experimental Results and Comparative Evaluation

Table I shows the experimental results for all the sensors at an operating frequency of 84 MHz. Only the change of magnitude of impedance is shown here (the impedance with air is considered as unity); in practice, phase information is also used. It is seen from Table I that both meander- and mesh-type sensors respond very well to conducting and magnetic materials but not so well to dielectric materials. On the other hand, the interdigital sensor responds very well to dielectric materials. The experiment has been conducted by mixing cream with water to change the percentage of fat content and the actual experimental values obtained for all three types of sensors are shown in Fig. 11. It is seen that the response of the interdigital sensor is very distinct. The change of transfer impedances for meander- and mesh-type sensors is not significant. The operating frequency is kept at 500 kHz. One of our immediate applications is to make a sensing system to estimate the fat content in the meat of pork. The main target is to employ combined sensors to develop a multisensor array detection system to detect the combination of conducting, magnetic, and dielectric materials. Detection of unexploded plastic landmines is under consideration.

TABLE I
Comparison of Results

System Under Inspection	Magnitude of Impedance @84 MHz		
	Meander	Mesh	Interdigital
Air	1	1	1
Copper	0.9127	0.8764	1.0152
Aluminium	0.9119	0.8669	1.0152
Iron	0.9077	0.7742	0.9985
Milk	1.0206	0.9698	0.9023
Water	1.0189	0.9733	0.9252

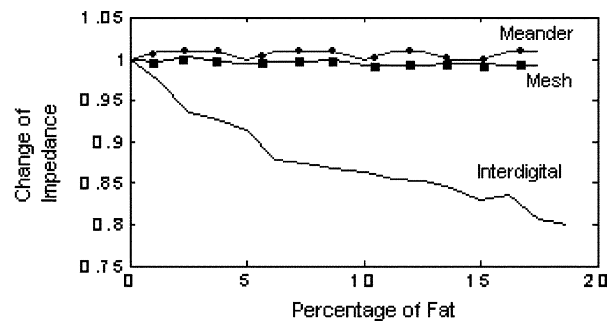

Fig. 11. Change of impedance of different sensors with fat content.

V. Conclusion

Novel planar electromagnetic sensors of meander, mesh, and interdigital types have been fabricated. The sensors have been characterized and their comparative performance has been evaluated. The sensors are used for the nondestructive evaluation of system properties. The development of a multisensor array detection system is under consideration to detect unexploded plastic landmines.

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