A Planar Electromagnetic Sensors Aided Non-destructive Testing of Currency Coins

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Abstract: This paper has described use of different types of planar electromagnetic sensors to test integrity of currency coins from several different countries. Three types of planar electromagnetic sensors, Mesh, Meander and Interdigital configuration have been used for testing. An effective method to test the integrity of coins using these three types of sensors has been explored. Finite Element model for mesh type sensor has been developed using FEMLAB. Some results from the finite element analysis and experimental results have been presented.

Keywords: *Planar electromagnetic sensors, meander, mesh and interdigital types, currency coins, integrity, non-destructive testing.*

I. Introduction

Sensors are widely used in scientific research and as an integral part of commercial products and automated systems. A sensor is a device which is used to record the presence of something or changes in something. Sensors gather information from the environment and act as transducers, converting the energy form associated with the information that is sought into a form in which it can be easily processed. The energy forms typically involved in sensing processes include chemical, electrical, magnetic, acoustic, mechanical, optical and thermal [1, 2].

The general properties of a good sensor are: (i) optimum measurement accuracy, (ii) durability, (iii) ease of calibration and reconditioning, (iv) sensitivity and good resolution, (v) provision of reproducible measurements, (vi) long term stability, (vii) fast response (important for control), (viii) continuous operation, (ix) insensitivity to electrical and other environmental interference, (x) low operation and maintenance cost.

Sensors play an important part in real-world systems, straddling a variety of applications such as industrial, medical, robotic, military, consumer and automotive applications. Sensors are critical to today's society since they provide the connection between the "real" world and the world of process control and computers. The overall accuracy and the reliability of the control system is determined by the sensors accuracy. Environmental concerns along with health and safety issues have necessitated in an increased use of sensors in the areas discussed above. Sensor technology has been successful in improving energy efficiency and service and product quality and reducing emissions. Selecting a sensor depends on many factors such as availability, cost, power consumption, environmental conditions etc. Sensors are integral when it comes to controllability, reliability and profitability of a process.

The sensors designed and fabricated for the non-contact measurement of material properties are of planar type and can be used in curved, bent surfaces [3]. The operation principle is based on the electromagnetic field. A high frequency electric or magnetic field is created by the exciting coil of the sensor in the system under test. The system usually interacts with the high frequency electric or magnetic field and modifies either or both. The modified field is usually detected by a separate coil known as the sensing coil or by the exciting coil itself. The modified field is usually manifested by a change of impedance or transfer impedance of the sensor. The impedance or the change of impedances is related to the system properties in a very complex way. The impedance is used for the indirect determination of system properties.

The planar electromagnetic sensors have been used to test the integrity of currency coins in a non-destructive and non-invasive way. To this date people rely on years of experience to detect counterfeit or fake copies of coins. There are many different names used to describe counterfeit coins, some quite accurate, others euphemistic or colloquial. Commonly used names include copy, forgery, restrike, reproduction and fake. The word fake, forgery and counterfeit are usually accurate [4]. Counterfeit coins of high instinct value will usually be lightweight, too thick or made of the wrong material such as lead and these will usually look, feel and sound completely wrong. We realise all these properties being used for detecting counterfeit coins much use to a beginner. Therefore we aim at developing and testing a novel system which can be used by a beginner to test the integrity of different coins and thus allowing them to detect counterfeit or fake copies of coins very easily. We will also be looking at using these integrity measurements for other novel applications.

An effective method to test coins for their integrity can be achieved by using different types of planar electromagnetic sensors. There are several methods such as eddy current inspection, remote field testing, flux leakage and barkhausen noise that use the electromagnetism as the principle of operation. We will be using the Eddy current testing (ECT) method for our inspection in to the integrity of coins.

Mainly coins are used in vending machines, porker machines, gaming machines and etc.

II. Planar Electromagnetic Sensors

Electromagnetic sensors are widely used in various fields of modern technology and engineering. Planar electromagnetic sensors have been used for many applications: inspection of printed circuit board [5], near-surface material properties [6], electroplated materials [7], cavity inspection in metal [8], interaction with moisture [9], inspection of saxophone reeds [10], dairy product monitoring [11] and meat inspection [12]. Three types of planar electromagnetic sensors have been used for testing the integrity of coins.

There are three types of sensors: Meander, Mesh and Interdigital types. Eddy current testing principle is used for the Mesh and Meander type sensors and the parallel plate capacitor is used for the Interdigital type sensor.

Mesh and Meander type sensors are shown in figure 1. These types of sensors have two coils, exiting coil and sensing coil as shown in figure 2. A sensing coil is in one side and an exciting coil is on the other side. The exciting coil and the sensing coil are separated by a polyamide film of 50μm thickness. When the high frequency current flows though exciting coil it generates an electromagnetic field around the sensor. This high frequency electromagnetic field while interacts with the system under test, in turn generates eddy currents which modifies the field produced by the exciting coil. The resultant modified field is detected by the sensing coil.

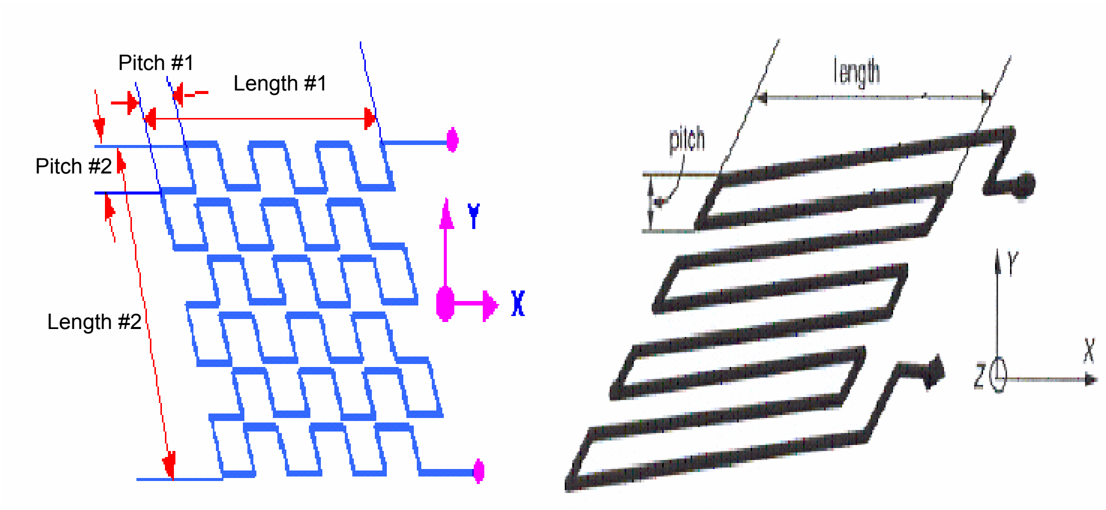

Figure 1: Configuration of planar electromagnetic sensors, mesh and meander type

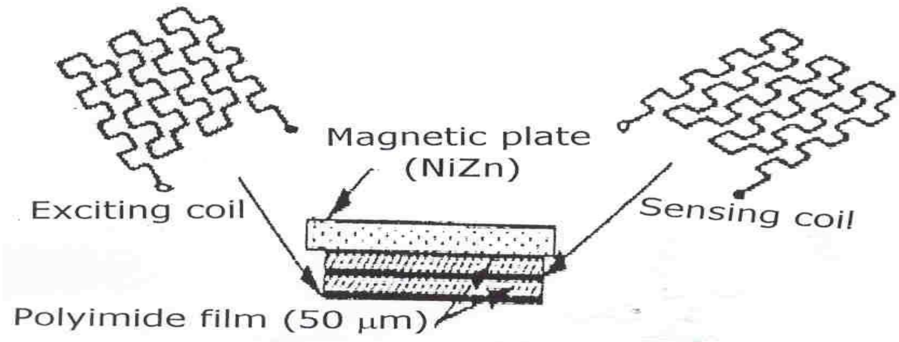

Figure 2: Structure of the Mesh type sensor

The main parameters for meander and mesh types sensors are pitch and length. All these factors can vary depending on the applications. The size of the sensor depends on the number of pitches and the size of the pitches used.
Operating principle of the interdigital sensor is very similar to the parallel plate capacitor. One set of electrodes connected to an alternating voltage source and the other set are connected to ground. An electric field is formed between those electrodes. The electric fields pass through the system under test. The depth of penetration of the electric field lines depend on the distance of the positive and negative electrodes. The figure 3 shows the field lines l_1, l_2 and l_3 for three different configurations. Depending on the permittivity of the system under test, it can influence the electric field lines. This is represented by a change of capacitance formed between the electrodes and consequently the impedance of the sensor. The impedance of the sensor is measured for estimation of properties of the systems under test. The interdigital sensor responds very well at moderately low frequency of operation which provides an opportunity to develop a low cost sensing system.
Figures 4, 5 and 6 show the fabricated sensors of meander, mesh and interdigital configuration.

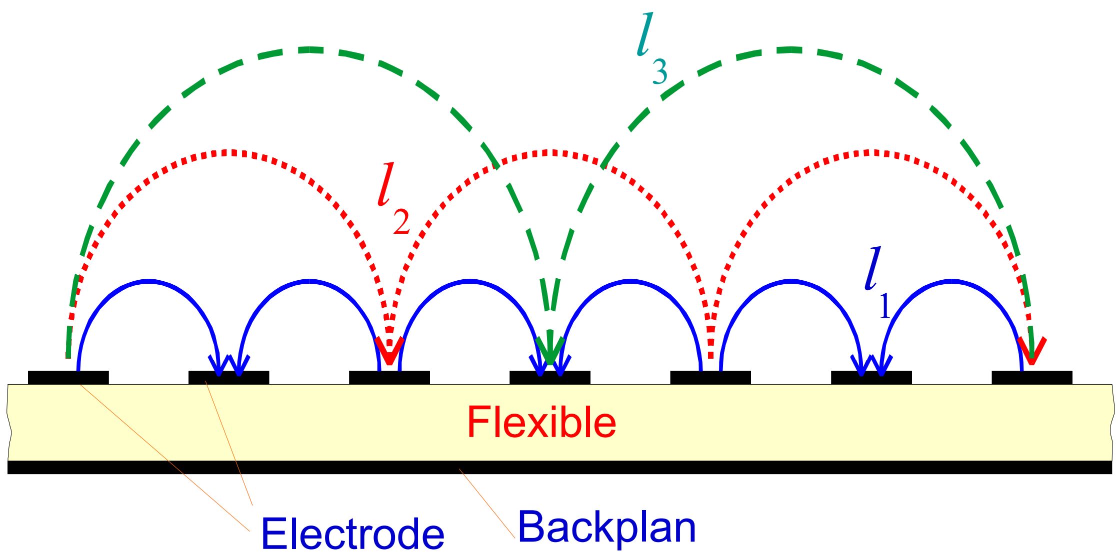

Figure 3: Field distribution of planar interdigital type sensor

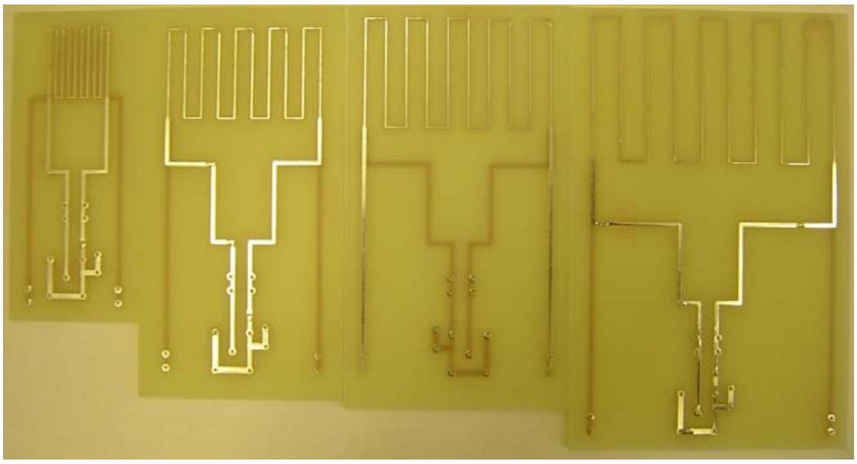

Figure 4: Fabricated meander type sensors, four sizes

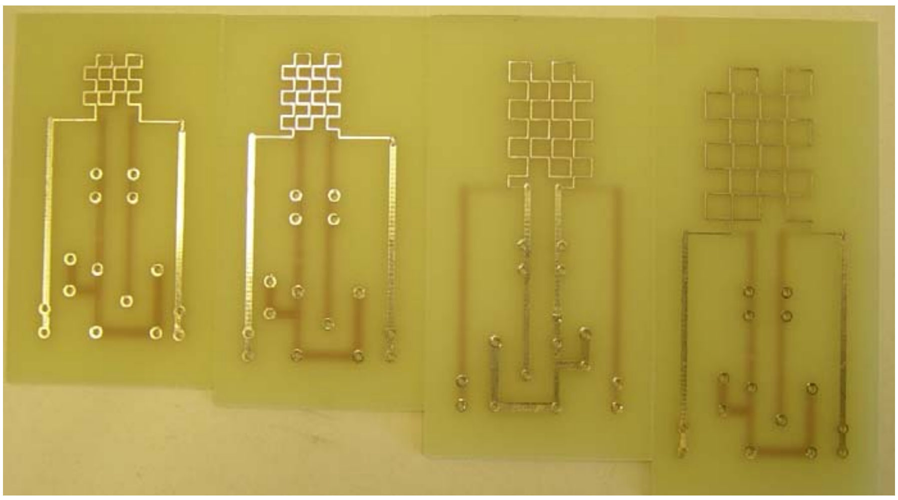

Figure 5: Fabricated mesh type sensors, four sizes

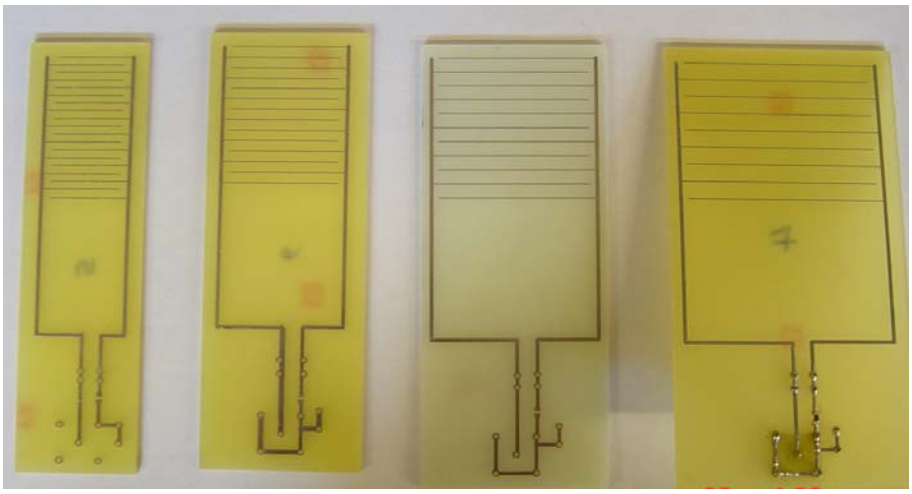

Figure 6: Fabricated interdigital type sensors, four sizes

III. Existing Method

In vending machine, coin locker, gaming machine, parking facility coin tester cum reader are already in use. The operating principle of a typical coin tester is described here [13]. User deposits coin into coin slot on outside of machine as shown in figure 7. Coin slot is dimensioned to the width and height for the thickest and largest diameter coin to be accepted. Coin rolls down a chute and past identification probe that determines the denomination by the coin's material properties. The probe consists of two solenoids with their axis perpendicular to the longitudinal wall of the chute. Current is run through one solenoid which then generates a **B** field perpendicular to the coin axis of revolution. The magnetic field passes through the coin, is attenuated by the coin's material properties and geometry before being received by the solenoid at the opposite end. The **B** field passing along the axis of the second coil generates a specific pattern of electric current, which can be matched with the correct coin.

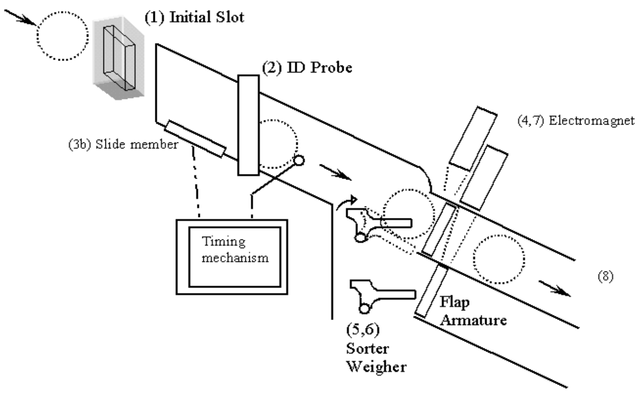

Figure 7: Coin Testing Apparatus Schematic

IV. Finite Element Modeling

In this section the field distribution of planar sensors has been carried out to investigate the response of the sensor to coins. The purpose is to observe the influence of the senor to coins made in different countries as shown in figure 8. The finite-element software package FEMLAB has been used for modeling. Figure 9 shows the finite element model of a mesh sensor along with a coin. But to avoid a large memory requirement and a long computation time only one pitch has been used for modeling. The magnetic flux density on each axis has been recorded at the position of the sensing coil. Figures 10, 11, and 12 show the distribution of field lines for three different conductivities of coins low, medium and high. The eddy current generated in the coin interacts with the fluxlines produced by the exciting current. It is seen from the figures 10 to 12 that the interaction increases with the increase in conductivity values. This will have an effect on the flux density. It is expected that overall flux density will decrease with the increase in conductivity.

Figure 8: Coins from different countries

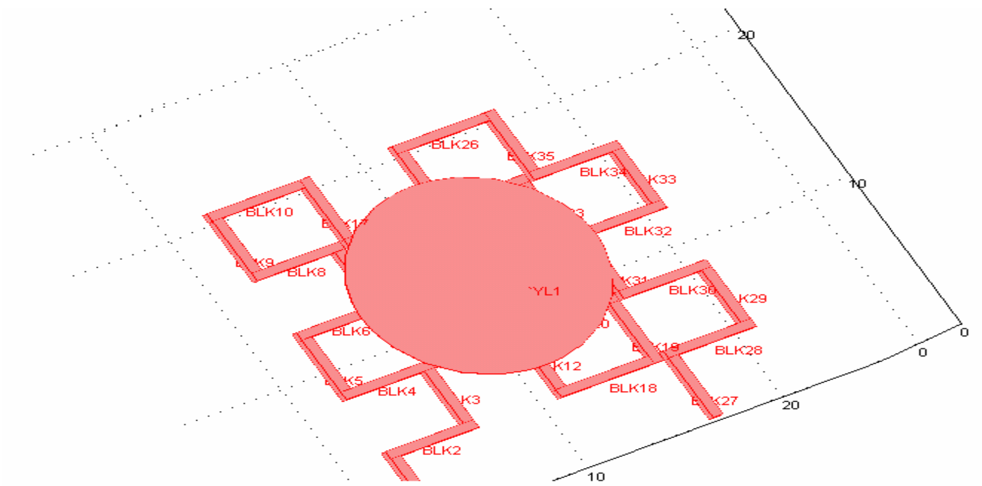

Figure 9: Finite Element Model for coin testing for mesh type sensor

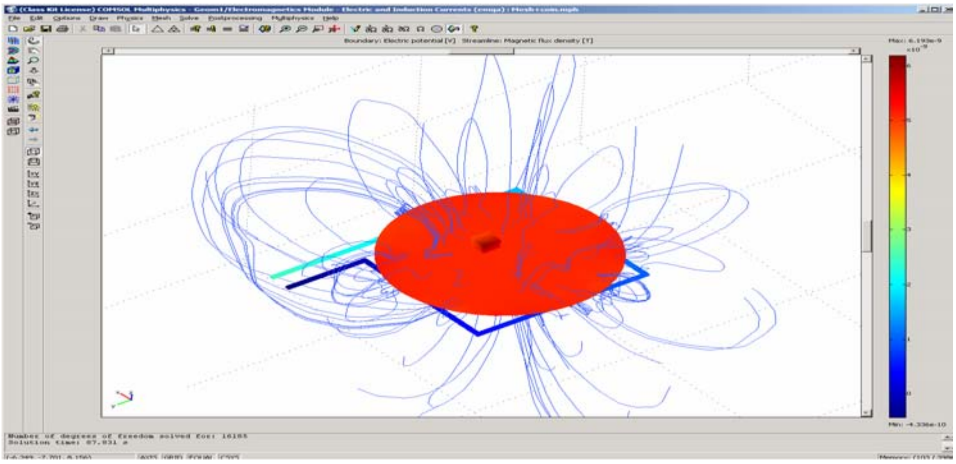

Figure 10: Magnetic flux lines for Mesh sensor obtained from FE model **(**Low Conductivity)

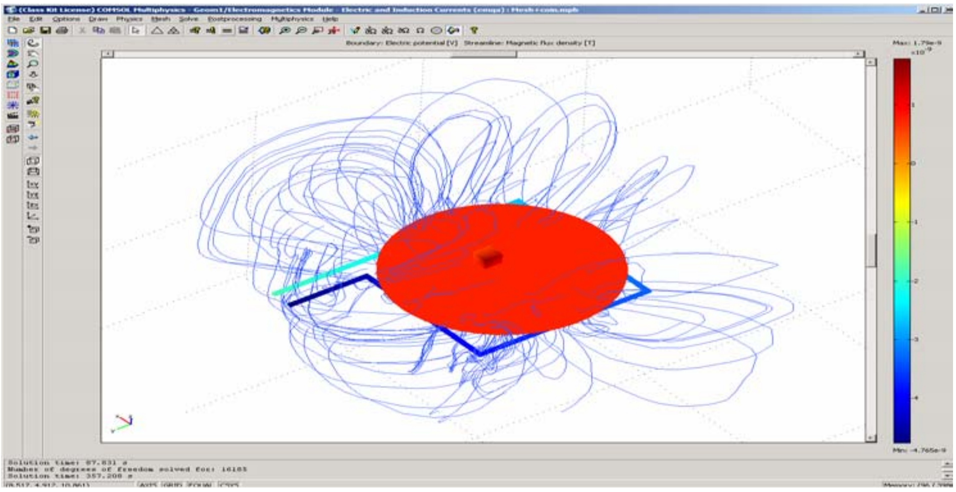

Figure 11: Magnetic flux lines for Mesh sensor obtained from FE model Medium Conductivity

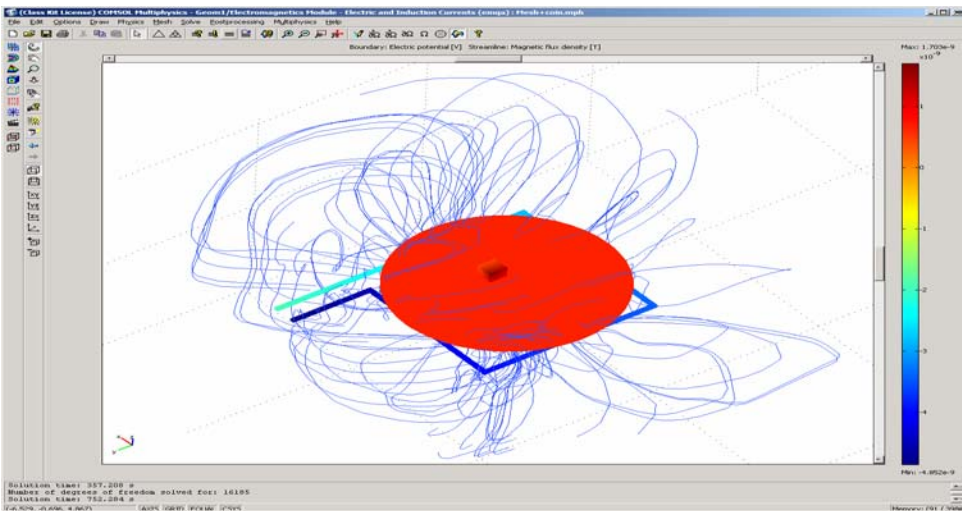

Figure 12: Magnetic flux lines for Mesh sensor obtained from FE model High Conductivity

Figure 13 show the variation of flux density as a function of conductivity of the coin. It is seen that the x-component of the flux density increases with the increase of conductivity where as y and z component as well as the normal value of flux density decreases with the increase of conductivity. The measurement of flux density components will be useful to obtain a detailed material characteristics.

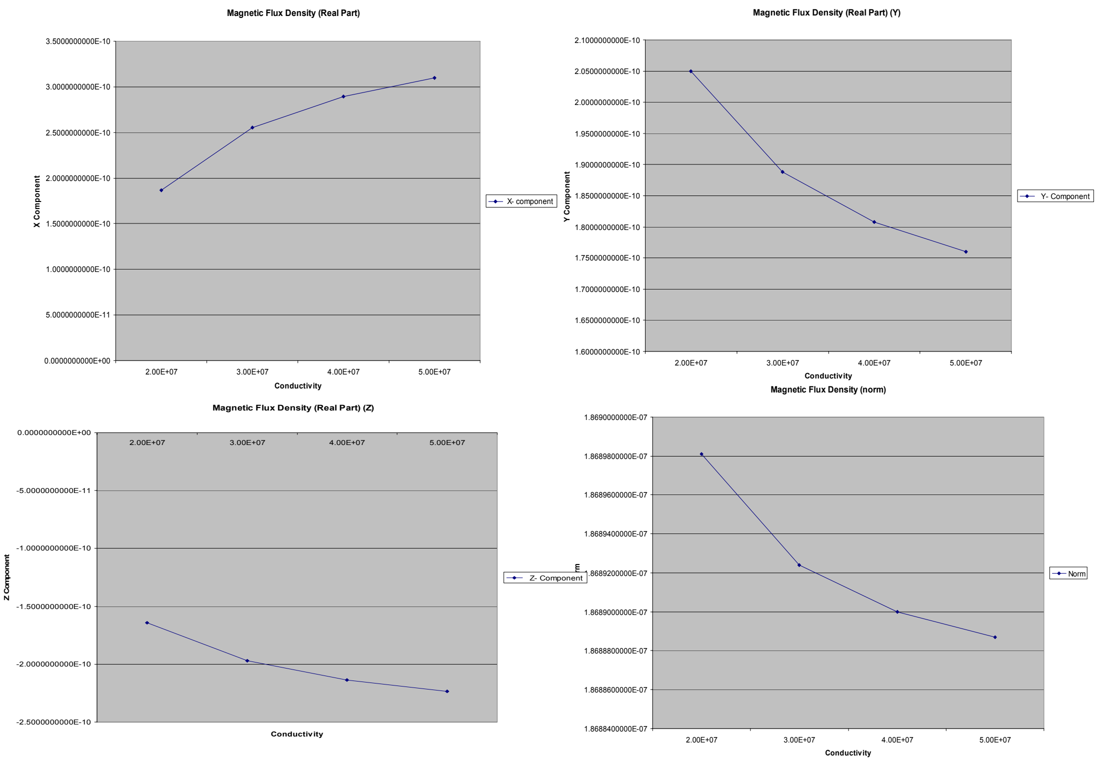

Figure 13: Variation of flux density with conductivity of coin

V. Experimental results

a. Network Analyzer

Figure 14 shows the experimental set-up based on a network analyzer for coin testing. The response of the network analyzer for different types of coins has been observed for a frequency range of 300 kHz to 1.3 GHz. Figure 15 shows the response of the network analyzer in the transmission mode for a few coins made of different countries. It is seen different types of coins have produced different profiles. It is seen from figure 15 it produces different peak values for different types of coins.

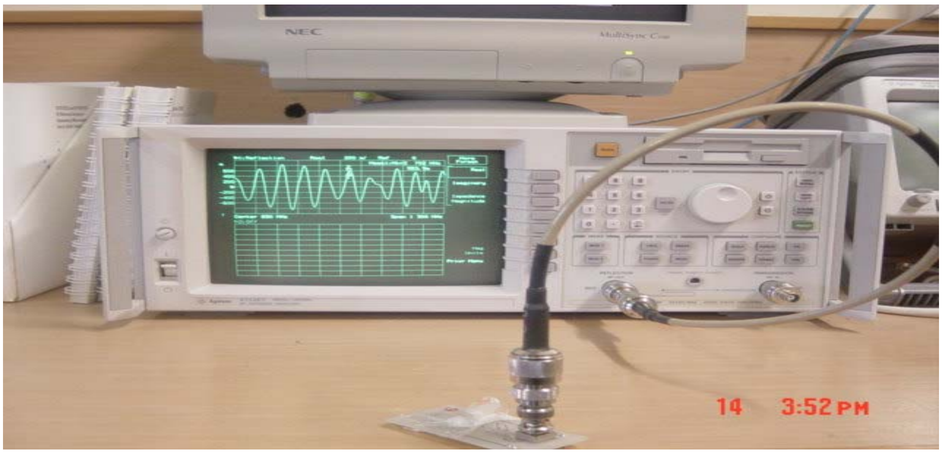

Figure 14: Experimental setup (network analyzer)

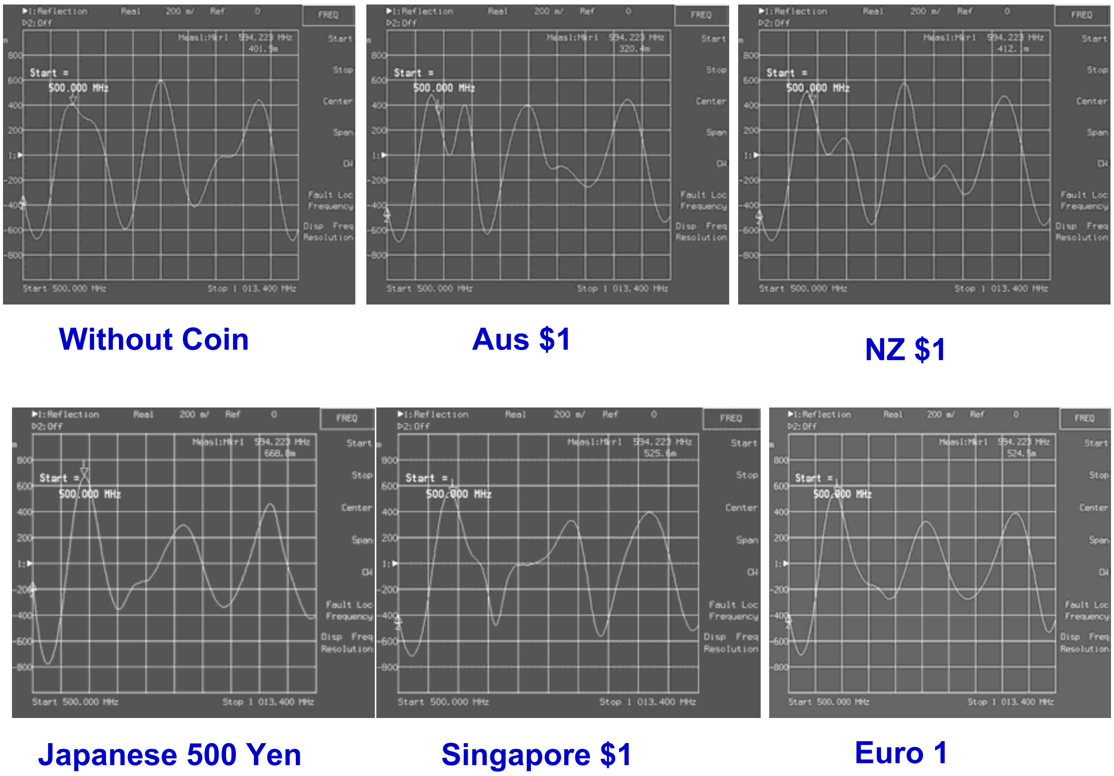

Figure 15: Network Analyzer response for different types of coins

b. A low cost sensing based approach

A low cost sensing system has been developed to be used as an alternative of the costly network analyzer. The results of only the mesh type sensor have been presented here. The impedance (both real and imaginary) of the sensor are measured for varying operating frequency. Figure 16 shows the variation of real and imaginary part of the impedance as a function of operating frequency for different coins. Figure 17 shows the real part of the impedance for coins of a few countries at an operating frequency of 1 MHz. It is seen that the respond of the sensor is quite different from each other.

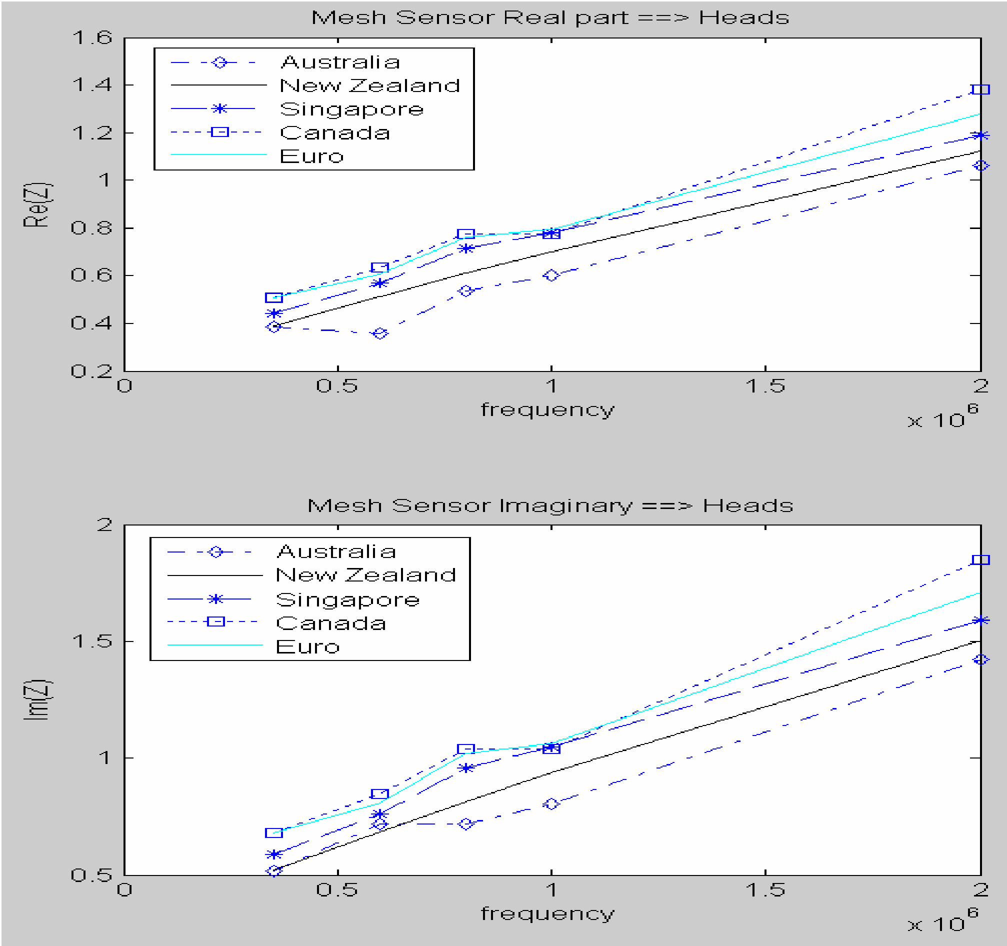

Figure 16: Coins from different countries being testing using the Mesh Sensor

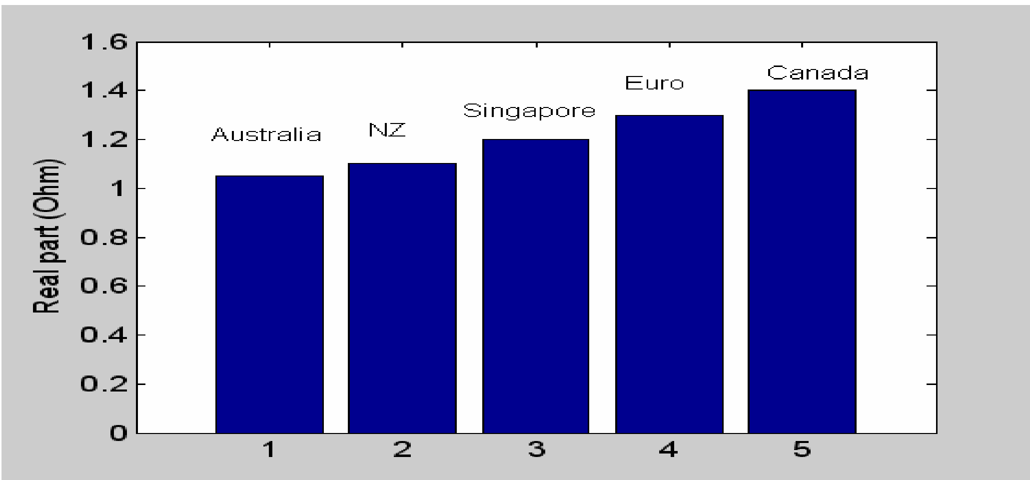

Figure 17: Impedance response for coins from different countries

Figure 18 shows the response of the sensors for six different New Zealand 1 dollar coins. It is seen the response of the sensor is quite consistent.

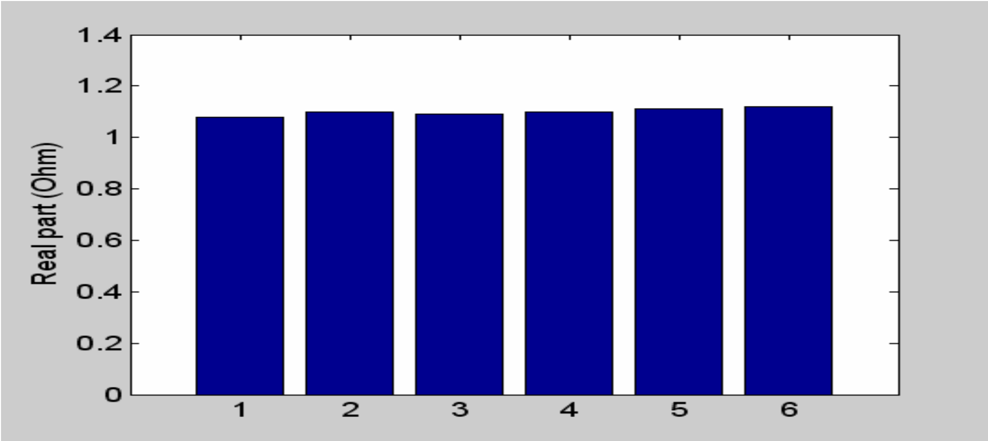

Figure 18: Impedance response for NZ $1

VI. Conclusion

Planar electromagnetic sensors can be used to inspect quality of currency coins. It is possible to provide the material characteristics too, which may be useful in some situation. The developed system can successfully discern between coins. Some more developmental work are carried out to obtain material characteristics which can be useful to many organizations.

VII. Reference

[1] W. Göpel and K.D. Schierbaum, 1991, "Sensors: A Comprehensive Survey (City Publishers)", vol. 2, pp. 5, 9.

[2] J. Fraden, 1997, "Handbook of Modern Sensors: Physics, Designs, and Applications (American Institute of Physics Press)", Second Edition, pp. 1-33.

[3] S.C.Mukhopadhyay, "Novel high performance planar electromagnetic sensors", The e-Journal on Nondestructive Testing, http://www.ndt.net/, ISSN 1435-4934, August 2005 issue.

[4] "The Very Highest Quality Advice", http://www.24carat.co.uk/counterfeitcoinsframe.html.

[5] S.Yamada, H.Fujiki, M.Iwahara, S.C.Mukhopadhyay and F.P.Dawson, "Investigation of Printed Wiring Board Testing By Using Planar Coil Type ECT Probe", IEEE Transactions on Magnetics, Vol. 33, No. 5, Sept, 1997, pp 3376-3378.

[6] S.C.Mukhopadhyay, S.Yamada and M.Iwahara, "Evaluation of near-surface material properties using planar type mesh coils with post-processing from neural network model", International journal Studies in Applied Electromagnetics and Mechanics, IOS Press Vol. 23, pp. 181-189, 2002.

[7] S.C.Mukhopadhyay, "Quality inspection of electroplated materials using planar type micro-magnetic sensors with post processing from neural network model", IEE Proceedings – Science, Measurement and Technology, Vol. 149, No. 4, pp. 165-171, July 2002.

[8] S.C.Mukhopadhyay and G.Senaratne, "Investigation on the use of planar type electromagnetic sensor for the detection of cavity in electroplated material" Proc. of ISEMA 2003, international conference on Electromagnetic wave interaction with water and moist substances, pp. 360-368, Rotorua, New Zealand, Mar. 23-26, 2003.

[9] G.Senaratne and S.C.Mukhopadhyay, "Investigation on the interaction of planar electromagnetic sensor with moisture at radio frequencies" Proc. of ISEMA 2003, international conference on Electromagnetic wave interaction with water and moist substances, pp. 91-99, Rotorua, New Zealand, Mar. 23-26, 2003.

[10] S. C. Mukhopadhyay, J.D.M. Woolley and G. Sen Gupta, "Inspection of Saxophone Reeds Employing a Novel Planar Electromagnetic Sensing Technique", Proceedings of 2005 International Instrumentation and Measurement Technology Conference, May 17-19, 2005, Ottawa, Canada, IEEE Catalog Number 05CH37627C, ISBN 0-7803-8880-1, Page number 209-213.

[11] S. C. Mukhopadhyay, C. P. Gooneratne, S. Demidenko and G. Sen Gupta, "Low Cost Sensing System for Dairy Products Quality Monitoring", Proceedings of 2005 International Instrumentation and Measurement Technology Conference, May 17-19, 2005, Ottawa, Canada, IEEE Catalog Number 05CH37627C, ISBN 0-7803-8880-1, Page number 244-249.

[12] S.C.Mukhopadhyay, C. Gooneratne and G. Sen Gupta, "Non-invasive Testing of Quality of Pork Meat: Novel Planar Electromagnetic Sensors Based Approach", Proceedings of IEEE IMTC Conference, April 24-27, 2006, Sorrento, Italy, pp. 1947-1952.

[13] David Hu, "How a coin tester works",
http://web.mit.edu/2.972/www/reports/coin_tester/coin_tester.htm