Presented in 2011 IEEE International Symposium on Antennas and Propagation & CNC-USNC / URSI Radio Science Meeting
3-8 July 2011, Spokane Convention Center, Spokane, Washington, USA

Electrical Properties and RF Energy Response of Metal Loop Antennas for Wireless Sensing and Detecting of Conductive and Non Conductive Materials

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***Abstract*—A number of loop antennas designed to operate at UHF ISM band 2.4-2.5 GHz have been investigated. Four types of loop antennas were designed and fabricated including the circular wire loop, square loop, circular plate loop, and disk loop. The circular plate loop has been incorporated into the RF sensing and detection peripheral due to its excellent practical performance. It was examined in various types of wireless environments where the complex object/ material both conductive and non conductive existed. In this paper, each type of antennas was also tested, numerically and experimentally, to obtain its individual electrical properties such as S_{11}, *VSWR*, and *radiation pattern*.**

Keywords – ISM band; loop antennas;RF sensing and detection; wireless environment; conductive and non conductive materials; RF energy response

I. INTRODUCTION

The loop antenna is well known due to its simple model, inexpensive and multifunctional. Loop antenna can be in the form of square, triangles, ellipses, circles, and many other configurations. Because of simplicity in the analysis and construction, circular loop type appears as the most popular and received much attention [1]. The loop antennas are usually classified into two categories namely electrically small loop and electrically large loop structures.

Small loop antenna has a small radiation resistance which is usually smaller than its loss resistance. Thus, it is a poor loop radiator. It is rarely used for transmission purpose in radio communication system. Small loop antenna is usually applied in the receiving mode, such as at the portable radios or pagers, which the SNR is not as important as the antenna efficiency [1]. Large loop antennas are typically used in directional arrays, such as the helical antenna, Yagi-uda arrays, or quad arrays. To obtain the directional characteristic pattern, the circumference of the loop should be about the size of the free space wavelength. A typical application of this loop antenna is the antenna detector [1]. Many applications of RF sensing and detection of data/objects from the surrounding environment has been implemented to deploy various types of antennas [2-4]. Each antenna has a unique characteristic suitable for a different application.

This paper outlines several loop antennas including circular wire loop, square/rectangular loop, circular plate loop and disk loop. The evaluations, numerical and practical, were performed in order to select the best antenna performance to suitable for the integration in the developed RF sensing and detecting device.

II. VARIOUS DESIGN OF LOOP ANTENNAS

A. Circular Wire Loop

The first model of the loop antenna designed in this research was in the form of circular wire loop. The constructed antenna is visualized in Fig.1. The radius of the loop antenna (a) can be calculated from the following equation [1]:

$$a = \{b \ln^{-1} (\Omega/2)\}/2\pi \quad (1)$$

where: Ω = the thickness of the tube conductor

b = the radius of the tube conductor

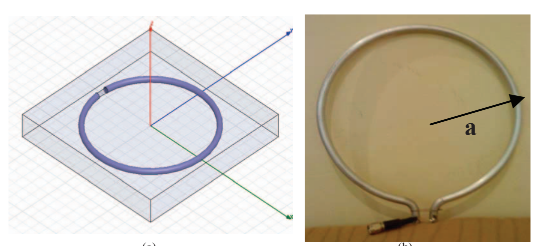
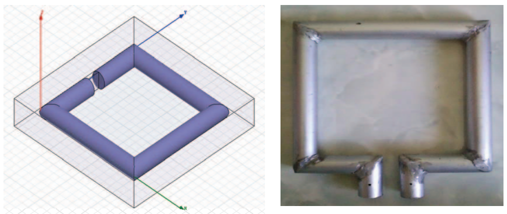


Fig.1: *Circular Loop* (a) Numerical Design (b) Fabricated Prototype

By considering the thickness and radius of tube conductor available in the market and the frequency operation required the size of the loop radius (a) was found $\geq$ 6 cm. Due to the technical problems in its construction the loop antenna provides the poor S_{11} performance. The best S_{11} is only around – 5 dB using HFSS V11.

B. Square Loop

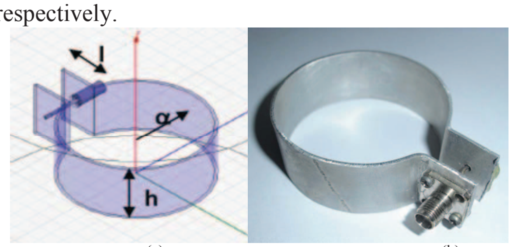
In practical situation, the rectangular/ square loop was built as one alternative solution when developing the circular wire loop. The technical problem encountered on bending a certain thickness and radius of the hollow tube conductor as shown in Fig.1 (b). The square loop antenna is depicted in Fig.2. The experimental testing performed to the square loop, both numerical and practical, resulted the poor S_{11} value (does not exceed the common acceptable threshold -10 dB level) in order to obtain the impedance bandwidth.



(a) (b)
Fig.2: *Squarer Loop* (a) Numerical Design (b) Fabricated Prototype

C. Circular Plate Loop

The circular plate loop model is shown in Fig.3. The antenna was built using the aluminum material of 1 mm thickness. The physical parameter such as *α, h* and *l* was determined. They have the value of 2.4 cm, 1.8 cm and 1.3 cm, respectively.

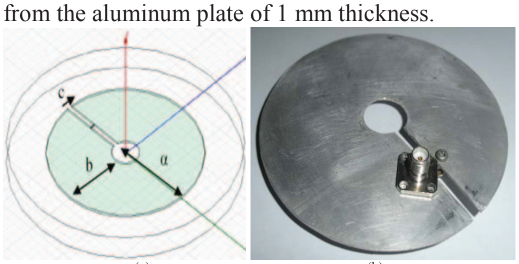


(a) (b)
Fig.3: Ring Loop (a) Numerical Design (b) Fabricated Prototype

The designed antenna can provide the large bandwidth 1.4 GHz ranging from 2.0 to 3.4 GHz based on the numerical computation. The best resonance frequency is achieved at 2.5 GHz with the S_{11} is approximately – 22 dB. VSWR at this frequency is 1.18.

D. Disk Loop

The numerical model and the fabricated prototype of a typical disk antenna are described in Fig.4. This antenna was built from the aluminum plate of 1 mm thickness.



(a) (b)
Fig.4: Disk Loop: (a) Numerical Design (b) Fabricated Prototype

Each parameter such as the radius of the outside circular plate α = 4.5 cm, the width of the plate b=3.7 cm, and the width of the excitation port c = 0.3 cm were used in the antenna construction.

III. RF SENSING AND DETECTING SYSTEM

Basically, the model of the developed RF sensing and detection system consists of two main parts, transmitter and receiver. This is shown in Fig.5. The transmitter itself has two units including the microcontroller unit and the RF transceiver module (XBee Pro). The microcontroller generates the instructions and data to XBee Pro and then to be transmitted continuously. At the RF transceiver, there is an oscillator capable to generate the RF signal around 2.4 GHz. This RF signal is used to modulate the data. After all the processes have been executed, i.e. data framing, coding and modulating, the data are continuously transmitted to the receiving unit. The RF waves propagate through various objects/materials along the transmission line.

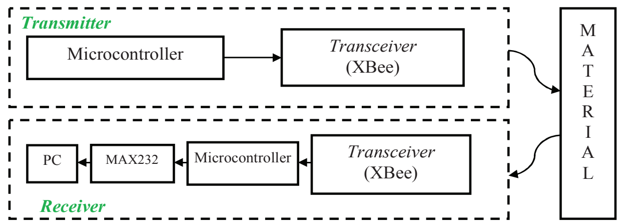
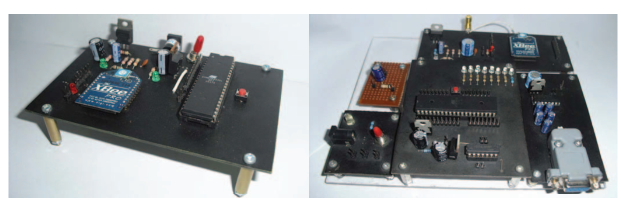


Fig.5. The RF sensing and detection system operated at ISM band 2.5 GHz.

As the radiated waves arrived at the conducting or non conducting material there are several possible events might be encountered. They may be reflected back and directed to the receiving unit, or they may be absorbed, scattered, spreading, etc. The received RF signals arrived at the receiver might be accumulated and influenced by these phenomena. The impact of the existence of the conducting material and non conducting one will be extensively discussed in the next section.

At the receiver, the designed loop is connected to an XBee transceiver module. This antenna has the input impedance varies as the received RF power altered. The main function of loop antenna is to receive the RF signal directed from the remote object/material. XBee Pro positioned in the transmitting part has the opposite functionality. It verifies the addressing and demodulates the received RF wave. RSSI port of XBee is connected directly to LPF circuit to obtain the RMS voltage so that it can be read by the ADC part of microcontroller unit. After this stage, the extracted data are fed to PC through pin 14 and 15 of MAX232 and displayed in a monitor. The prototype of the manufactured RF sensing and detection system is shown in Fig.6.



(a) (b)
Fig.6: The implemented RF sensing and detection system: (a) Transmitting unit; (b) receiving unit

The research project was partly supported from R&D Produk Telekomunikasi Grant funded through DIPA 2010, General Directorate of Post and Telecommunication, Ministry of Communication and Information, Republic of Indonesia; SK SEKJEN POSTEL No.11/DJPT.5/KOMINFO/IV/2010.

IV. Numerical and Experimental Examinations

A. Electrical Properties of Loop Antennas

Several electrical properties of the constructed loop antennas were obtained through simulation and measurement. Simulation was done using HFSS V.11. The practical characteristic was recorded using VNA E5071C (to obtain S_{11} and VSWR) and antenna trainer ED-3200C (to measure the radiation pattern). Not all the designed loop antennas will be discussed in this section however due to the excellent numerical and practical characteristics only the circular plate loop is extensively persented.

1) S11 Parameters

The reflection coefficient of circular plate loop antenna is relatively excellent. The good matching impedance at the resonance frequency 2.5 GHz can be achieved where VSWR 1.18. The bandwidth is provided greater than 1.2 GHz (numerically) and 0.62 GHz (experimentally).

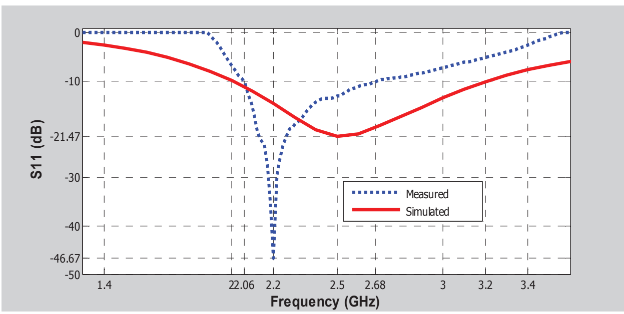


Fig.7: the reflection coefficient of circular plate loop antenna

2) Pattern Properties

The pattern properties, azimuthal and elevation, of the circular plate loop antenna is shown in Fig.8. The pattern characteristics, both numerical and experimental, are approximately omnidirectional. The RF energy can be illuminated or received almost at the same power level from any directions.

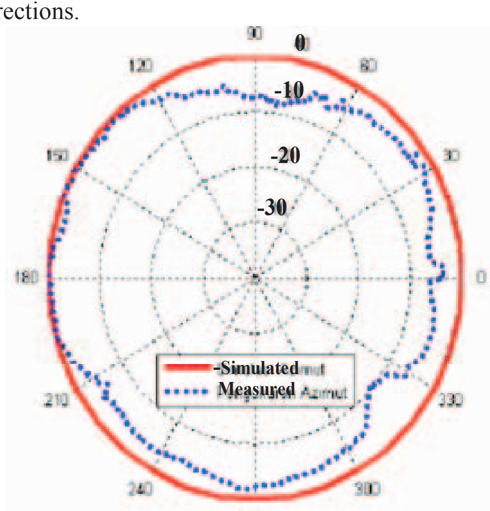


Fig.8 (a). Azimuthal pattern of circular plate loop structure

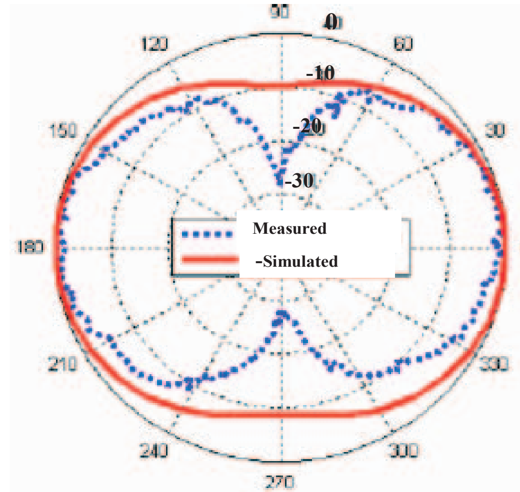


Fig.8 (b): Elevation pattern of circular plate loop structure

B. Various Testing Model of RF Sensing and Detecting System

The behavior of the circular plate loop antenna incorporated with the RF sensing and detection devices were actually examined in various wireless environments where a large variety of the conducting and non conducting materials exist in the vicinity. There are three kinds of non conductive objects/ materials used including the ground structures (consisted of sands, small rock, soil, dust etc), the plastic fiber material (sized 1mx1m), and the wall of building. The conductive material used in the experiment is the aluminum plate (sized 1mx1m). There are three configurations of testing scenario adopted to examine the electromagnetic wave response of the loop antennas in various wireless environment situations. These are described in Figs.9, 10, and 11, respectively. Fig.9 illustrates the measurement set up to evaluate the effects of the aluminum or a plastic fiber plate positioned at 5 m in front of the receiver unit. Both measurements were performed in Telematic Laboratory, Department of Electrical Engineering, UNHAS.

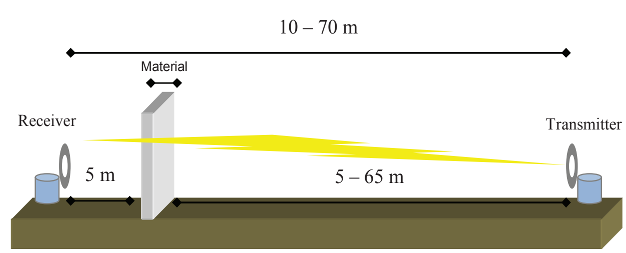


Fig.9: Testing the RF sensing and detection system as aluminum or fiber obstacle located between the transmitter and receiver.

The experimental observation drawn in Fig.10 is to measure the impact of the tall and thick of the grounding structure existed in the network. In this case, the receiver employing the loop antenna was placed at the distance 5 m from the edge of the hilly land located at the most beautiful, ancient, and historic port of Benteng Somba Opu (built around the 16th century by the Dutch Government).

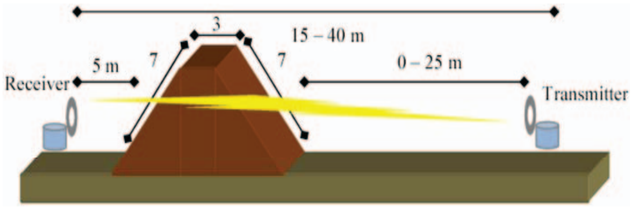


Fig.10: Testing the RF sensing and detection system as the tall and thick ground existed between the transmitter and receiver.

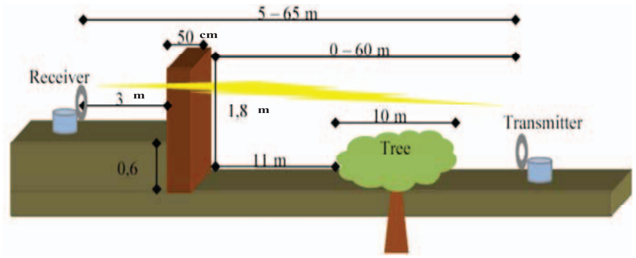


Fig.11: Testing the RF sensing and detection system as the tall and thick wall and other the surrounding objects existed between the transmitter and receiver.

Another interesting investigation is visualized in Fig.11. This experiment set up was intended to evaluate the impact of the complex situation/ wireless environment to the sensitivity of the deployed loop antennas inside a wireless peripheral. There are a number of objects which most of them are the non conducting structure existed at the vicinity of wireless devices. This testing part was done in another beautiful and antique port so called Roterdam Port at Makassar City (also built by Dutch Government in the 16th century).

In general, the RF energy response of the circular loop antennas incorporated into the RF sensing and detection system under various wireless environment conditions are illustrated in Fig. 12. There are the significant variations on the quality of signal reception at the receiver in case of various conductive and non conductive materials existed. The RF power response will be different for each material. The most degradation of the sensitivity occurred while the perfect conducting material such as aluminum, brash, copper and so on located near the loop antenna. Comparing to the non conductive materials the RF signal response altered around 10 % to 20%.

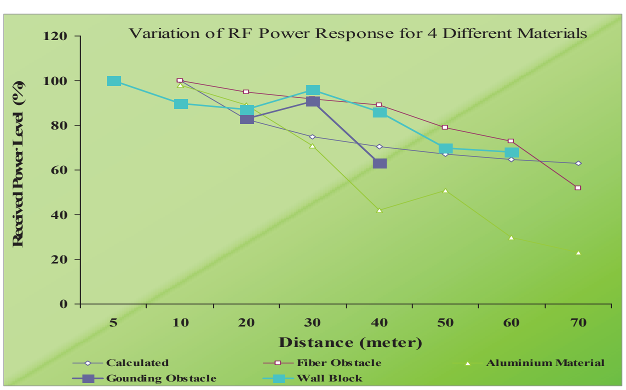


Fig.12: The RF energy response of the sensing and detection system employing one type of circular plate loop antenna.

V. Conclusions

Four different types of loop antennas applicable for wireless sensing and detecting the structural elements of both conductive and non conductive objects have been constructed and examined through the numerical computation and the practical measurement. Amongts the four antennas i.e. the circular wire loop, square loop, circular plate loop, and disk loop there are only one type of loop antennas, i.e circular plate loop, has been installed into the RF sensing and detecting system due to the poor electrical properties of the rests. This antenna was exploited to observe the performance of the system at various and complex wireless environment. It has been shown that the conductive materials/ objects located close to the antenna may degrade the RF power reception. The variability of RF power response due to the non conductive or conductive objet exist is 10% to 20%.

Acknowledgment

The authors would like to thanks to the Directorate of Standardization, the General Directorate of Post and Telecommunication, Ministry of Communication and Information, Republic of Indonesia for supporting the sufficient R&D grant to develop various antennas and for providing a number of high quality equipments to allow us to perform some experimental testing. The authors would extend their sincere thanks to anyone who contributed to the establishment of the MoU between CWMA, Griffith School of Engineering, Griffith University, Australia and Telematics Laboratory, Department of Electrical Engineering, Universitas Hasanuddin (UNHAS), Indonesia. The collaboration is mainly focusing in R&D and education activities. The sincere thanks should be also conveyed to Mr. Syathir Macawa for his generous helps for fabricating and testing the RF sensing and detection system.

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