Single Band Antenna Using Harmonic Trap Open Circuit Stub (OCS) Method for Electromagnetic Radiation Detector

Puteri Alifah Ilyana Nor Rahim[1,2], Syarfa Zahirah Sapuan[1,2], Shipun Anuar Hamzah[1,2], Mohd Zarar Mohd Jenu[1,2]
[1]Center for Applied Electromagnetic, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, Malaysia.
[2]Faculty of Electrical and Electronic Engineering, Universiti Tun Hussein Onn Malaysia, Parit Raja, Batu Pahat, Johor, Malaysia.
syarfa@uthm.edu.my

***Abstract*—This paper focused on the design and performance of Harmonic Suppression Antenna (HSA) that can effectively operate at frequencies of 900 MHz, 1800 MHz, 2100 MHz and 2600 MHz and can suppress the undesired harmonic frequencies. Proposed antenna can be used as a RF detector to sense the Electromagnetic Radiation from mobile base station. Harmonic suppression antenna (HSA) is able to suppress the harmonic frequencies to get a better antenna performance since the needed to have single band antenna as a RF detector. Open Circuit Stub (OCS) is the harmonic suppression techniques that has been used in this project and capable to suppress the harmonic frequencies in the range of 0 MHz to 7 GHz. The stubs as harmonic suppression element does not affect the radiation pattern which has the percentage of reduction is about less than 10 %. The simulation of the antenna design was conducted by using CST Microwave Studio software.**

***Index Terms*—Electromagnetic Radiation Detector; Harmonic Suppression Antenna (HSA); Open Circuit Stub (OCS).**

I. INTRODUCTION

Electromagnetic (EM) radiation consists of natural radiation and the man-made radiation that are produced either intentionally or as by-products. These radiation come across through wired and wireless transmitters/receivers, electrical/electronic devices and systems. Such Radio Frequency (RF) fields or EM fields are well prone and have the tendency to cause heating in the exposed part of the human body. This has developed deep concerns among the researchers about the human health implications. Today, in most countries the regulations of RF exposure are mandated in the form of Specific Absorption Rate (SAR), which is defined as the energy absorbed or dissipated in a mass and measured in watts per kilogram, is the parameter for characterizing the absorption of RF fields in the body.

However, other side of the picture portrays serious concerns over the existence of potential health hazards due to significant radiations emitted by the wireless communicating devices. In regards to this, technical specifications have also been recommended in International Committee on Nonionizing Radio Protection (ICNIRP) in Figure 1 and other consultative groups to the designers and manufacturers about the internationally regulated limits for the emitted radiations. [1-3]. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) is an international commission specialized in nonionizing radiation protection. The organization's activities include determining exposure limits for electromagnetic fields used by devices such as cellular phones [4].

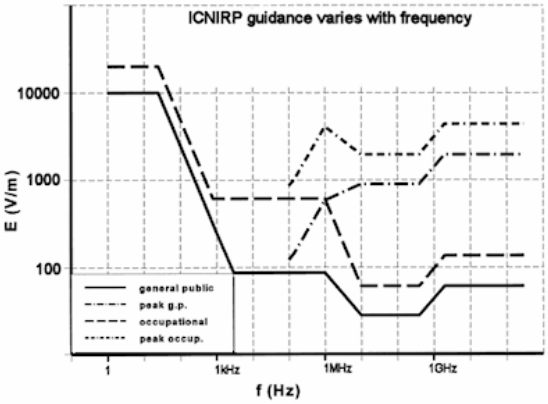


Figure 1: Reference levels for exposure to time varying electric fields [4].

The interaction of time varying electric fields in the human body results in the flow of electric charges and the magnitude of these fields depend upon the electrical properties of the body. Moreover, these external fields induce current into the body and their distribution depends upon the size, shape and the position of the body as it has been described in the ICNIRP report.

The ambient RF energy can be collected and rectified into electrical energy, as shown in Figure 2. The antenna is used to collect the RF signal from the source and filtered to pass through the desired signal. Then the RF signal is rectified to DC signal by rectifying circuitry [5-7]. There are four single band antennas required for the system. The antennas are required for four different operating frequencies that are 900 MHz, 1800 MHz, 2100 MHz and 2600 MHz respectively. The electric field values from that four antennas can then be compared with the limits proposed by ICNIRP. In the limits proposed by ICNIRP, each frequency give a different level of of Electric Field. Therefore, it is important to have a single band antenna which can give an output voltage for specific frequency.

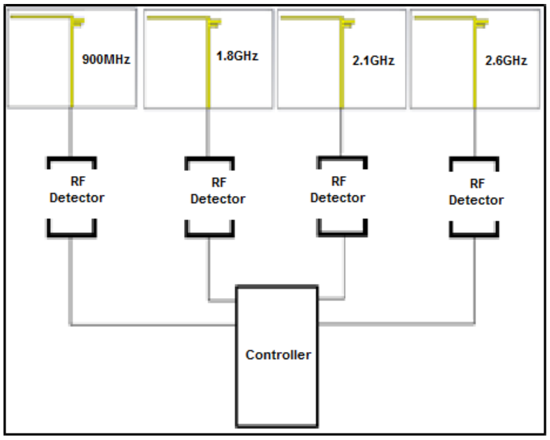


Figure 2: System block diagram for single RF detector system

Microstrip reconfigurable antennas have received a great deal of attention for their applications in wireless communications in recent years. The applications are in the various fields such as in the medical applications, satellites and in the military systems like in the rockets and aircrafts missiles. The usage of the Microstrip antennas now booming in the commercial aspects due to their low cost of the substrate material and the fabrication. Microstrip patch antenna spreading widely in all the fields such as mobile and satellite communication application, Global Positioning System applications, Radio Frequency Identification (RFID), Radar Application, Rectenna Application and many others. The existence of high frequencies mode may disrupt the operation of the system and will require filter circuit at the output. On top of that, as microstrip antennas conventionally integrated with active RF devices, especially power amplifiers, caused RF front end systems to have large size, complex structures and complicated design. These problems can be overcome by using harmonic traps antenna in an active integrated antennas (AIAs). AIAs are very extensive and worldwide but it suffers from undesired harmonic radiation. These unwanted harmonic radiations must be suppressed. As far as harmonic suppressed antenna (HSA) with switch is concerned, the harmonic reconfigurable antennas have been designed published previously in the literature. Basically, there are several methods have been researched in practice to suppress the harmonic frequencies. The implementation of antenna with harmonic suppression is to avoid fake radiation that normally produced at high-order resonant frequencies of the antenna. The electromagnetic bandgap (EBG), defected ground structure (DGS) and open circuit stub (OCS) are used in harmonic suppressed antenna (HSA).

DGS in [8] modify the guided waves properties to provide a filter and can easily define the unit element. It has simple structure and usually used in more complex structure of antennas. EBG HSA in [9] use a periodic structures with an obvious frequency band gap, which can suppress the propagation of surface-wave. Although the structures can help to reduce the mutual coupling of antenna array but the design is more complex as compare to DGS. OCS structure in [10] control the flow of current to the antenna. Resulting the input impedance of the antenna is well matched at the fundamental frequency while unmatched the harmonic frequencies. Although the system require a little bit of space to create the stub, the design is more direct and easier to be implemented. The performance of the overall system will be improved since the power is maximized at the fundamental frequency and the radiated power is suppressed at harmonic frequencies to achieve harmonic rejection characteristics. However, antenna harmonic suppression will have maximum power transfer at its design frequency if 50Ω is the input impedance of antenna and completely matched with the characteristic impedance of transmission line to obtain maximum energy transfer between transmission feed line and an antenna.

This paper introduces a reconfigurable printed dipole antenna to select one of several frequency bands, which cover a wide frequency range. Due to wideband coverage of these frequency bands, selecting only one of the frequency bands at each time can make difficulties, if the higher order modes are taken into account. In fact, when the antenna operates at lower frequency bands the higher order modes can be matched at higher frequencies and this is not desired. In this paper, harmonic trap using open circuit stub (OCS) is proposed to eliminate the higher order modes. It is experimentally shown that by using switches and harmonic traps, a reconfigurable printed dipole antenna can be designed to select several frequency bands, which cover a wide frequency range.

II. ANTENNA DESIGN AND CONFIGURATION

In this section, higher order modes elimination by using harmonic trap is explained. In this process, the antenna is designed on FR4 substrate with thickness of 1.6 mm. The dimension of the substrate for antenna with frequency of 900 MHz is (140 x 85) mm while for antenna with frequencies of 1800 MHz, 2100 MHz and 2600 MHz, the substrates are (70 x 85) mm. The antennas are designed and simulated using CST Microwave Studio software.

Table 1 shows the configuration of typical dipole antennas with frequency of 900 MHz, 1800 MHz, 2100 MHz and 2600 MHz are combined with tapered balun, which is the transition between 72 Ω parallel paths of transmission line to 50 Ω SMA connector that connected to the antenna. The balun has a tapering maximum width of 64 mm and height of 64 mm from the start of microstrip lines. The width of transmission line is 3 mm on a track of parallel lines. The antennas are printed on both sides of FR4 substrate board with 1.6 mm thickness and 4.4 permittivity (dielectric constant). The antennas are connected to 50 Ω SMA connector. The details of dimension of the antennas are shown in table 2.

To suppress the harmonic frequencies, different lengths of stubs were used as shown in table 3. By using the formula of $\lambda/4$, the length of stubs can be calculated. The position of the stubs must be in parallel on both sides of the FR4 substrate. The length of stubs are differ from each other depending on its desired frequency with the width of 3 mm for each stub. The dimension of the stubs has been optimized by a parametric study. The antenna is connected to 50 Ω SMA connector. In fact, the open circuit stub at the frequency of 3f0 shorts the antenna. The details of stubs length are shown in table 4.

Table 1
Configuration of typical design antennas

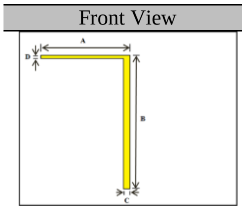
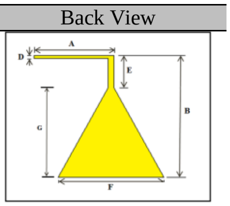
Front View	Back View
	

Table 2
Dimensions of design antenna

Label	Dimension (mm)			
	Frequencies (MHz)			
	900	1800	2100	2600
A	68.00	31.88	26.75	22.40
B	79.00	79.00	79.00	79.00
C	3.00	3.00	3.00	3.00
D	1.50	1.50	1.50	1.50
E	15.00	15.00	15.00	15.00
F	64.00	64.00	64.00	64.00
G	64.00	64.00	64.00	64.00

Table 3
Configuration of design antennas with stubs

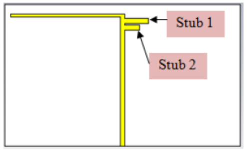
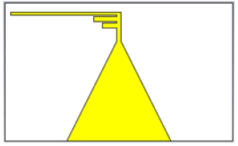
Front View	Back View
	

Table 4
Length of stubs for each harmonic trap of different desired frequency

Frequency	Lengths of stub (mm) Stub 1	Stub 2	Stub 3
900 MHz	10.11	7.80	-
1800 MHz	8.39	-	-
2100 MHz	5.80	-	-
2600 MHz	6.29	-	-

III. RESULTS AND DISCUSSION

Figure 3 shows the simulated return loss of the reconfigurable printed dipole antenna without and with harmonic trap that operated at 900 MHz, 1800 MHz, 2100 MHz and 2600 MHz respectively. The circle represents the harmonic frequencies for operating frequencies of 900 MHz, 1800 MHz, 2100 MHz and 2600 MHz. There are three harmonic frequencies that need to be suppressed for operated frequency of 900 MHz, two for 1800 MHz, also two for 2100 MHz and there is one harmonic frequencies for operated frequency of 2600 MHz. In Figure 3, it shows the harmonic frequencies that already suppressed after applying a stub length on antenna design. From the results, the return loss of antennas without stubs and with stubs that operated at 900 MHz are -21.402dB and -18.995dB respectively. For a wider overall frequency band, where the higher order harmonics fall inside the overall band, more switches are needed to shorten the harmonic trap. In this case, the antenna selects only one of the frequency bands each time. The radiation patterns of the antenna were measured at the resonance frequencies of the selectable frequency bands. Figure 4 shows the simulated radiation patterns in E-plane for the 900 MHZ, 1800 MHz, 2100 MHz and 2600 MHz frequency bands for dipole antennas in the angle theta component are 180°, 90°, 160°, and 170° respectively. The radiation pattern of the antenna is obtained in farfield region. The antenna polarization is omni directional.

Figure 5 shows the comparison of measurement return loss of typical dipole antenna. The measured result is compared between dipole antenna without stub and with stub. From the results shown below, both of the antennas are effectively operate at 900 MHz. The antenna without stubs was operated at 885 MHz with return loss value of -22.973 dB and antenna with stubs was operated at 893 MHz with return loss value of -19.786 dB. All the harmonic frequencies were able to suppress. The first harmonic frequency at 2655 MHz with return loss value of -19.686 dB is suppressed to -2.362dB. The second harmonic frequency at 4380 MHz with return loss value -23.250 dB is suppressed to -2.683dB while the third harmonic at 5990 MHz with return loss of -22.459 dB is suppressed to - 4.683dB.

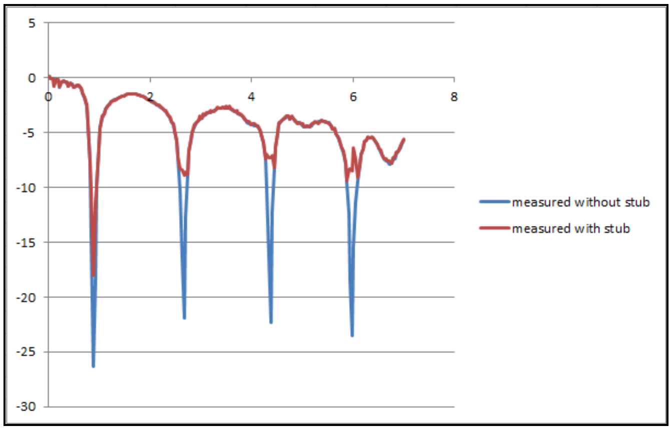


Figure 5: Measured return loss of dipole antenna for 900 MHz without and with stubs

IV. CONCLUSION

Harmonic trap open circuit stub (OCS) can be used to eliminate higher order modes in reconfigurable frequency band antennas. The results shows that the stubs as harmonic suppression element does not affect the radiation pattern which has the percentage of reduction is about less than 10 %. Therefore, proposed dipole antena can be used as a single band receiver and eventually the received signal can be converted from RF signal to DC voltage using a RF detector. This is important to ensure the received Electric field at specific frequency can therefore be compared with standard limits by ICNIRP.

REFERENCES

[1] D. M. Pozar, Microwave Engineering (3rd ed.), Singapore, John Wiley and Sons, Inc, 2005.

[2] ICNIRP Guidelines for limiting Exposure to time varying electric magnetic and Electromagnetic fields (up to 300 GHz). Health Physics vol. 74, no. 4, pp. 494-522, 1998.

[3] Wiart 2001.Data on COST 244bis `Short term Mission on Base Station Exposure.

[4] "Framework for Developing Health Based EMF Standards". World Health Organization. Retrieved 15 January 2016.

[5] J. O. McSpadden, and K. Chang, "A dual polarized circular patch rectifying antenna at 2.45 GHz for microwave power conversion and detection", *IEEE MTT-S International Microwave Symposium Digest*, San Diego, CA, pp. 1749-1752, 1994.

[6] McSpadden, J.O., Dickinson, R.M., Fan, L. and Chang, K., "A novel oscillating rectenna for wireless microwave power transmission", *IEEE MTTS International Microwave Symposium Digest*, Baltimore, MD, pp. 1-8, 1998.

[7] M. S Ghaffarian, G. Moradi and R Zaker, "Harmonic Suppressed Slot Antennas Using Rectangular/Circular Defected Ground Structures", *International Journal of Antennas and Propagation*, pp. 1-7. 2012.

[8] Jin Hua-song, Qiu Dong-dong, Rao Jia-ren, Zong Peng, and Darwin R. Becerra, "Application of EBG and DGS structure on Antenna Array", *International Conference on Image Analysis and Signal Processing (IASP)*, pp. 1-4, 2012.

[9] Ali Mirkamali, Peter S. Hall, Mohammad Soleimani, "Reconfigurable Printed Dipole Antenna with Harmonic Trap for Wideband Applications", IEEE, pp. 188-191, 2006.

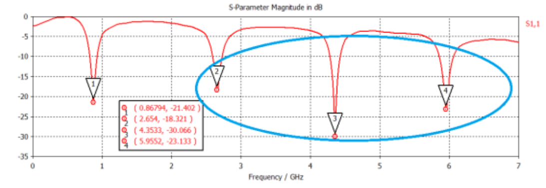
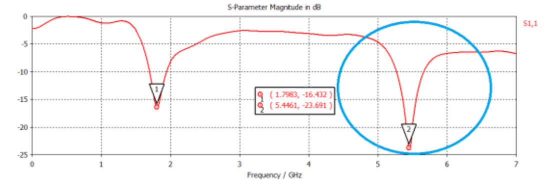
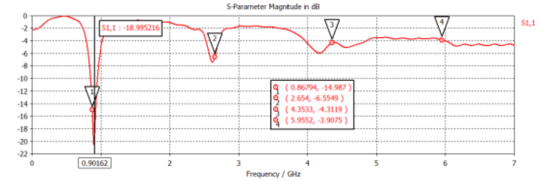
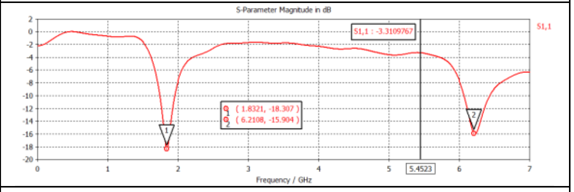
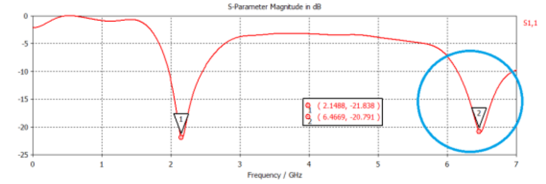
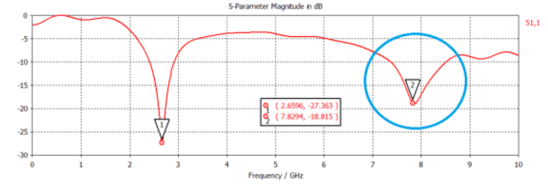
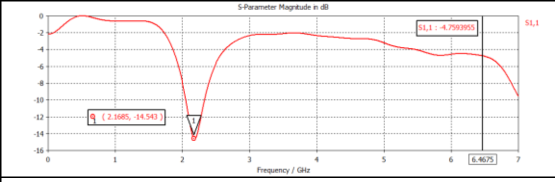
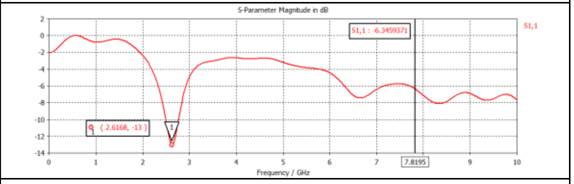
Without stub		
With stub		
Frequency	a) 900 MHz	b) 1800 MHz
Without stub		
With stub		
Frequency	c) 2100 MHz	d) 2600 MHz

Figure 3: Simulated return loss of dipole antenna without stubs

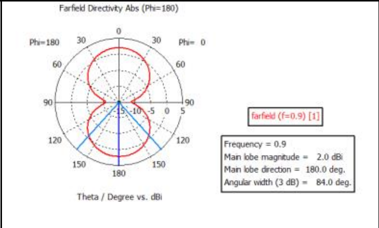
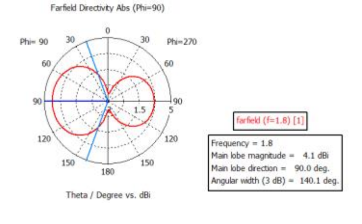
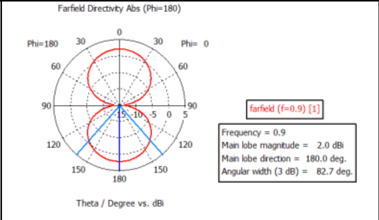
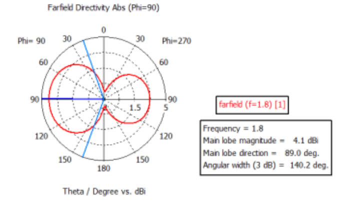
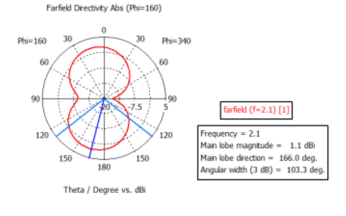
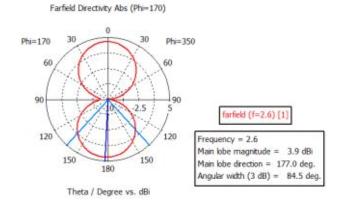
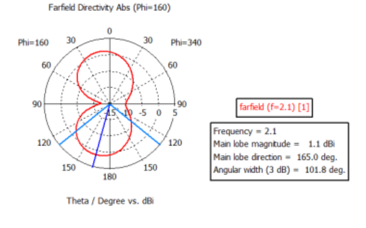
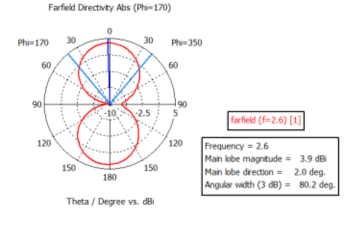
Without stub		
With stub		
	a) 900 MHz	b) 1800 MHz
Without stub		
With stub		
	a) 2100 MHz	b) 2600 MHz

Figure 4: Radiation pattern (polar plot) of design antenna without and with stubs