A Parametric Study on Dual-Band Meander Line Monopole Antenna For RF Energy Harvesting

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Abstract— **This paper studies the dual-band monopole antenna based on meander line structure for Global System for Mobile Communications (GSM) band applications, which is also has the potential to be used for RF energy harvesting. A meander line antenna with a conductor line is investigated during the design using the Computer Simulation Tool (CST) software. The antenna is fabricated on a double-sided FR-4 printed circuit board using an etching technique. The comparison between simulation and measurement results for the return loss and radiation patterns are observed and are in good agreement. A bandwidth of 97 MHz and return loss of -19.29 dB is obtained at the first frequency band, i,e. 915 MHz, while a bandwidth of 46.2 MHz with a return loss of -16.27 dB are obtained at the second frequency band, i.e. 1800 MHz. This study is an early investigation in designing the RF energy harvesting to support green technology and sustainable development particularly for Wireless Sensor Network (WSN) as well as Radio Frequency Identification (RFID) applications.**

Keywords—Dual-band; monopole; GSM band; return loss; energy harvesting

I. Introduction

Energy harvesting or energy scavenging is basically a conversion process of the ambient energy into electrical energy [1]. In recent years, there has been a growing interest in the deployment of wireless sensor networks (WSN) that are used in applications such as in structural monitoring, habitat monitoring, healthcare systems and precision agriculture.

However, the deployment of a large number of sensor nodes results in periodic battery replacements which is impractical and cost consuming. One technique to overcome the aforementioned problems is to deploy a network comprising self-powered mechanism through a Radio Frequency (RF) energy harvesting system. This method significantly reduces the costs of replacing batteries periodically which also saves time.

An energy harvesting system consists of two main subsystems which is receiving antenna and rectification circuitry. Fig. 1 below shows the basic block diagram of an energy harvesting system.

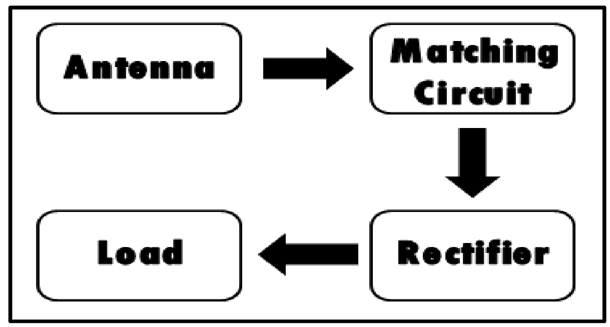


Figure 1: Block diagram of energy harvesting system

An efficient antenna is required to transfer wireless power efficiently. The antenna captures the RF signals from the ambient, and subsequently the rectifier circuit will extract the power from those signals and converts them into DC voltage.

Nowadays, electrically small, multiband antennas are widely used in the various communication systems. Typically, electrically small antenna has a low radiation efficiency and narrow bandwidth. To reduce the size of the antenna, a number of effective ways are possible to be done including by using high permittivity substrates [2] shorting pins [3][4] and meander line [5][6][7]. For GSM communication system, dual-band antennas are required since the system operates at two frequencies which are at 915 MHz and 1800 MHz.

Meander line is a winding curve or bended line. Meander line technology allows the designers to design the antenna with a small size, but it provides overall wideband performance [8]. The Meander line could be in two different forms which are as meander strip lines (meander-type patch) or as slotted meander lines. The meander line antenna is designed based on the wavelength of the desired frequency [9]. Having the advantage to miniaturize antenna, slotted meander line antenna is best chosen for antenna size reduction [10].

Monopole antennas have been used in numerous applications especially in mobile communication systems due to their simple structure and desired omnidirectional radiation pattern. However, in order to meet the miniaturization of existing mobile communication equipment, the design of low profile and compact monopole antenna is more particularly important. A simple way to miniaturize a monopole antenna has been demonstrated in [2]. A meander conductor line is printed on a dielectric substrate to reduce the size of a monopole antenna, but the resulted antenna is only applicable for single-band operation. Hence, the antenna has been enhanced so that it could operate for dual band applications. This can be achieved by extending a straight conductor line from the end of a rectangular meander monopole.

The proposed dual-band monopole antenna is fed by a coplanar waveguide (CPW) line where the central conductor is separated from a pair of ground planes. The CPW offers several advantages including the ability to work at lower frequencies and ease of fabrication. The design of the meander line antenna has small dimension and approximately 50 Ω input impedance. The design begins with the electromagnetic (EM) simulations using Computer Simulation Tool (CST) software. The proposed dual-band meander monopole antenna is designed to operate at 915 MHz and 1800 MHz as it approaches the GSM interoperability.

In this paper, a new class of dual band monopole antenna based on meandered microstrip lines structure for RF energy harvester is presented. Hence, the antenna can be recommended to integrate with matching and rectifying circuit to exhibits DC signals.

II. Antenna Design

Fig. 2 shows the geometry of the proposed GSM dual-band monopole antenna. This antenna is printed on an FR4 substrate with a thickness of 1.6 mm and relative permittivity of 4.4. A 50 Ω CPW transmission line is used to excite the antenna.

The basis of the antenna structure is a rectangular meander monopole, which has the dimensions of height 27mm and width 10.5 mm. A conductor line of height 25.5mm is extended from the end of the rectangular meander monopole. This extended conductor line is located relatively close to the rectangular meander monopole while the space between the two conductors is 1 mm.

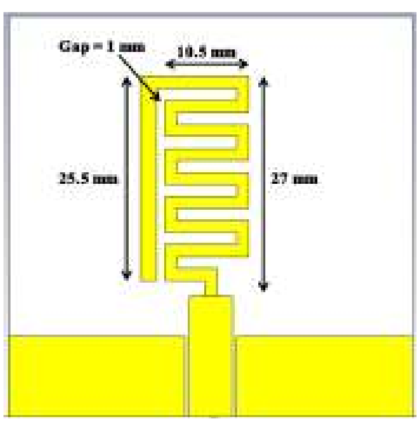


Figure 2: Structure of dual-band monopole antenna

In this design, the extended conductor line increases the current path of the antenna's first resonant mode, which reduces the required size of the proposed antenna for a fixed operating frequency. Moreover, as the two conductors are close to each other, the electromagnetic coupling is created between the two conductors, which leads to the second resonant mode excited with good impedance matching. That is by introducing the extend conductor line, the proposed compact dual-frequency monopole antenna with good impedance matching can be obtained.

III. Experimental Results And Analysis

In order to provide an accurate antenna design, the investigation on the effects of physical dimension to the meander line has been conducted. The parameters of the meander line antenna that are considered in this paper are conductor line width (C1), conductor line length (C2), the number of turn (N) and meander line width (w) as shown in Fig. 3.

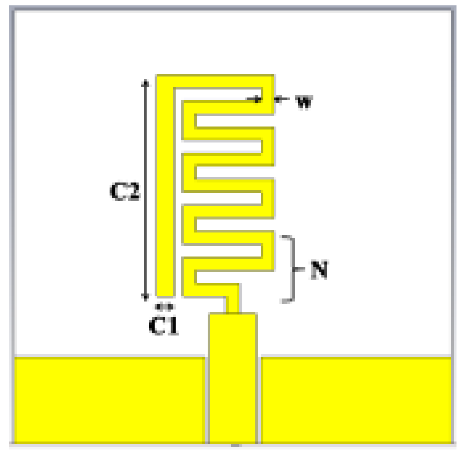


Figure 3: Geometry of the dual-band monopole antenna

Table 1 shows the frequency response and return loss based on the effects of different conductor line width, (C1).

TABLE I. The Effects of Conductor Width (C1)

Width (mm)	915 MHz		1800 MHz	
	Frequency response (MHz)	Return Loss (dB)	Frequency response (MHz)	Return Loss (dB)
0.5	975	-19.29	1850	-11.27
1.5	957	-18.13	1848	-13.43
2.5	934	-17.58	1837	-14.12
3.5	915	-15.32	1920	-15.37
4.5	900	-13.11	1920	-17.48

It can be observed in Table 1 that the conductor line with a width of 0.5 mm gives the best return loss at lower frequency. However, the antenna resonates at 975 MHz. For the upper frequency, conductor line with a width of 4.5 mm demonstrates the best return loss, i.e. -17.48 dB, but the frequency shifted to 1920 MHz.

The effect of conductor length (C2) to the design is summarized in Table 2.

TABLE II. THE EFFECTS OF CONDUCTOR LENGTH (C2)

Length (mm)	915 MHz		1800 MHz	
	Frequency response (MHz)	Return Loss (dB)	Frequency response (MHz)	Return Loss (dB)
13.5	1306	-19.34	2100	-24.88
16.5	1215	-17.89	1949	-26.34
19.5	1135	-17.23	1886	-27.25
22.5	1051	-15.47	1862	-28.12
25.5	971	-12.32	1802	-29.75

The dual-band monopole antenna shows that C2=25.5mm gives a return loss of -12.32dB at 971MHz while a return loss of -29.75dB is obtained at 1802MHz. It is observed that the frequency response of both frequencies shifts to lower frequency as the length of conductor line, C2 increases.

Table 3 shows the antenna performance based on number of turn, N. From the table, it can be observed that the number of turn, N = 4 produced the best return loss of -16.68dB at 910MHz and -16.38dB at 1732MHz respectively. The frequency response and return loss seems to be unstable when the number of turn is increased.

TABLE III. THE EFFECTS ON NUMBER OF TURN (N)

Number Of Turns (N)	915 MHz		1800 MHz	
	Frequency response (MHz)	Return Loss (dB)	Frequency response (MHz)	Return Loss (dB)
3	900	-14.69	1680	-14.39
4	910	-16.68	1732	-16.38
5	900	-20.32	1692	-19.57
6	880	-10.08	1810	-11.78
7	920	-8.3	1762	-15.42

The antenna's performance is also affected by the meander line width and the analysis is shown in Table 4. The return loss doesn't have any increment or decrement pattern but it varies according to the width of meander line.

In general, the responses of the antenna can be analyzed through the study as indicated in Table 1 – 4. The return loss decreases when the conductor width (C1) is increased. The same effect is experienced by the conductor length (C2), i.e. where the return loss decreased proportionally with the length of the conductor. However, this only occurred at lower frequency band.

Based on the analysis that has been studied, the dimension of the meander line antenna which operates at 915 MHz and 1800 MHz frequency can be optimized and determined as shown in Table 5.

TABLE IV. THE EFFECTS ON MEANDER LINE WIDTH (W)

Meander line width (mm)	915 MHz		1800 MHz	
	Frequency response (MHz)	Return Loss (dB)	Frequency response (MHz)	Return Loss (dB)
0.5	867	-12.34	1841	-10.49
1.0	761	-6.35	1666	-9.14
1.5	970	-8.74	1820	-17.19
2.0	940	-10.86	1467	-12.23
2.5	974	-11.94	1358	-15.42

TABLE V. OPTIMUM PARAMETERS OF DUAL-BAND MONOPOLE ANTENNA

Parameter	Length (mm)
Conductor width, C1	2
Conductor length, C2	25.5
Number of turn, N	4
Meander line width, w	1.5

The antenna is then fabricated in-house and the photograph of the prototype can be seen in Fig. 4. An experimental measurement also has been conducted to validate the simulation results.

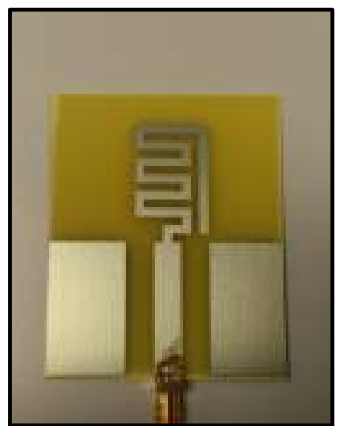


Figure 4: Antenna prototype of dual-band monopole antenna

A. *Return Loss, Bandwidth and Gain*

Fig. 5 shows the return loss for dual-band monopole antenna. The simulation result shows that a return loss of -13.38dB is achieved at 915 MHz while the return loss at 1800 MHz frequency is -15.42dB. The bandwidth of the antenna is 97.0 MHz for lower frequency and 461.6 MHz at higher frequency respectively.

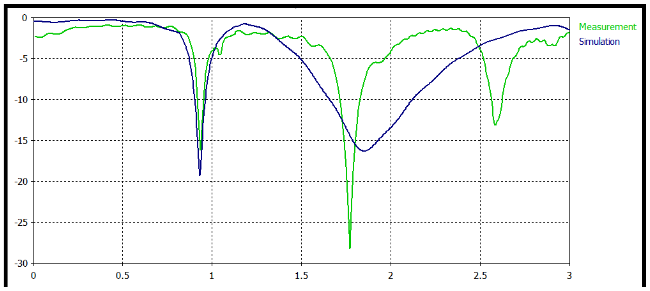


Figure 5: Simulation and measured return loss of planar dual-band monopole antenna

It is observed that the lower frequency measurement agrees well with the simulation and both results have a comparable bandwidth. However, the bandwidth at the upper frequency is narrower than the simulated result. The discrepancy is due to the variation of permittivity in the substrate and also manufacturing tolerance. The small amounts of losses are due to the losses from microstrip, copper loss through conductivity and also losses through SMA connectors. Detailed results of frequency response, return loss, bandwidth and gain are tabulated in Table 6.

TABLE VI. Simulation and Measurement Result of Dual-band Monopole Antenna

Freq. of interest	f_r	**Return Loss (dB)**	**Bandwidth (MHz)**	**Gain (dB)**
915 MHz	Sim. 930 MHz	-19.29	59.3	0.82
	Meas. 930 MHz	-16.18	33.1	-0.23
1800 GHz	Sim. 1850MHz	-16.27	461.6	1.43
	Meas. 1770MHz	-28.16	114.2	1.14

The measured return loss is in-line with the simulation response where both managed to achieve lower than -10 dB. From the measurement data, two resonant modes at about 915 MHz and 1800 MHz are successfully achieved.

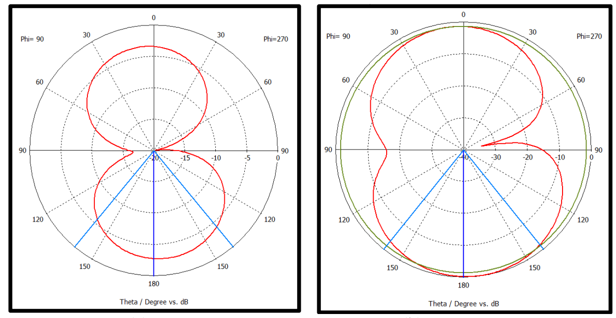
The gain parameter is measured using the following equation;

$$\text{Gain Received} = P_R - P_T - G_T + P_L + C_{L1} + C_{L2} \qquad (1)$$

where P_R = power received; P_T = power transmit; G_T = gain transmit; P_L = path loss; and C_L = cable loss.

B. Radiation Pattern

The radiation characteristics are also investigated and can be seen in Fig. 6 below. The antenna radiates directionally at 915 MHz while the pattern is almost omnidirectional at 1800 MHz.

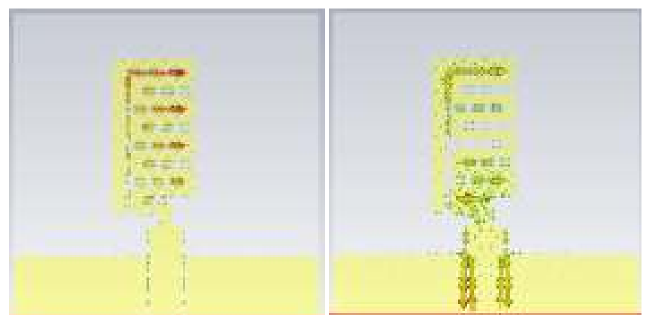


(a) (b)

Figure 6: Simulated radiation pattern at (a) 915 MHz (b) 1800 MHz

C. Surface Current

Fig. 7 shows the surface current of the dual-band monopole antenna. The current for lower frequency is radiated by the meander line and conductor line. While current radiates at the CPW feeding line for upper frequency. The conductor line provides an additional resonant frequency compared to a conventional meander line monopole antenna for a dual-band operation.



(a) (b)

Figure 7: Simulated radiation patterns of dual-band monopole antenna at (a) 915 MHz (b) 1800 MHz

It is recommended in future works that for the designed antenna to be further explored to be applied on RF energy harvesting. An experimental measurement in the laboratory can be conducted by varying the distance between the transmitting and receiving antenna.

The input power of the transmitting antenna could be injected directly from an RF signal generator ranged from -20dBm until 20dBm. The output voltage and output power at the receiving antenna is then can be measured by using a spectrum analyzer. In this case, the performance of the antenna can be investigated in order to predict the most optimized performance to capture as much energy as possible. Thus, it is suggested to discover and design the most suitable antenna topology for RF energy harvesting.

The antenna is then can be integrated with a rectifier to convert the RF signals into the DC voltage. The efficiency of this system could be enhanced by embedding a matching circuit to the rectifier for an improved output. An experimental test can also be conducted by varying the distance, D between the transmitting and receiving antenna in future works. The input power of transmitting antenna can be injected directly from a signal generator ranged from -20dBm to 20dBm. The output voltage and output power at the receiving antenna is then can be measured by using a spectrum analyzer.

IV. Conclusion

In this paper, the performance of monopole dual-band antenna has been presented. The antenna operates at 915 MHz and 1800 MHz for GSM band application. The antenna measurement return loss is better than the simulation value at the lower frequency. However, the resonance frequencies are slightly shifted. Nevertheless, it is able to cover the frequency of interest range. The gain at 1800 MHz is higher that the gain at 915 MHz frequency. Hence, the antenna radiates well at 1800 MHz frequency with an almost omnidirectional pattern compared to the radiation pattern at 915 MHz which is suitable for RF energy harvesting systems where it can receive the signal in 360°. Further works can be done to experimentally explore the designed antenna for RF energy harvesting systems.

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