Radiator for Wireless Charging Application Based on Electromagnetic Coupling Resonant

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***Abstract*—This paper presents the design and characterization of radiator for wireless charging application. The radiator is designed based on electromagnetic coupling resonant using a microstrip patch in spiral shape to work at operating frequency around 10MHz with the dimension of patch deployment of 50mm × 60mm. The design process includes characterizations of varied patch length and of gap separation between 2 stacked radiators to achieve the optimum performance. After obtaining the optimum design, the radiator is deployed on a side of FR4 Epoxy dielectric substrate with the thickness of 0.8mm, whilst the other side is applied for a groundplane. The realized radiator is then measured experimentally to obtain its characteristic responses to be compared with the design results. From numerical characterization, the radiator works at operating frequency of 10MHz with S_{11} value of -29.79dB and S_{21} value of -1.62dB. Whilst from experimental characterization, the operating frequency of fabricated radiator is 9.21MHz with values of S_{11} and S_{21} of -20.22dB and -2.72dB, respectively.**

Keywords*—Electromagnetic coupling resonant; radiator; wireless charging; wireless power transfer

I. Introduction

Nowadays, human beings cannot be separated from their needs for portable devices such as mobile phone for communication, a notebook for work and linked-up to the internet, and mp3 player to enjoy and listen the music. All the equipments are commonly using rechargeable batteries as their main source. Thus the adapter or battery charger, for human dependence on battery, is often continuously mounted on main power outlet sources to facilitate recharging process. As the growth of technology development in portable device, recently the number of equipments that need battery charging are quite high. Not only being related to the current consumption and voltage requirement for battery charging process, the use of different charging adapter for each device also increases.

Furthermore, the use of multiple portable devices including notebooks, mobile phones, gadgets or mp3 players is becoming very inefficient and can be unmoved freely, since in terms of power charging the charger devices should be as close as possible to the source and use a limited power cable net. Therefore, the concept of wireless charging which is one of the real applications for wireless energy transmission has triggered for further development. Here, the device can be charged without having connection electrically to the adapter and power cable nets, but merely to set on a wireless charger. Wireless charging technology grows up from the need to overcome the charging problems with conventional method in which the device should be connected to the power source using cable and adapter [1]– [2].

Basically, wireless power transfer is a system that has a process whereby electrical energy can be transmitted from a power source to the electrical load without cable. There are various techniques for transferring electrical energy without the use of cables or wires, some of them which have been going around in the market is using RF technology or frequency radiation from the air on radio waves [3]– [4]. In general, this technology has been widely applied to transfer wirelessly the electrical energy for low power charging device. Unfortunately, due to the weak of received power on each radio or wireless receiver circuit, the power should be strengthened in the receiver circuit using the external power source. Another method is using direct radiation by applying an antenna directly from the source to the receiver without any obstruction, namely line-of-sight (LOS). Apart from those techniques, in this paper the technology of wireless power transfer is not referred to the energy radiating concept instead using near fields approach. The concept of wireless energy transfer implemented here is developed from the concept of electromagnetic coupling resonant [5]– [8].

II. Brief Overview of Radiator Design

Based on the concept of electromagnetic coupling resonant, the resonant circuit for transferring electrical energy wirelesly, called as radiator, is designed using a technology of microstrip patch. The proposed radiator should accomplish some requirements such as having the operating frequency around 10MHz and value of S_{11} and S_{21} at operating frequency less than -10dB and close to 0dB respectively. Whilst the total size for patch deployment does not exceed than 50mm × 60mm. Theoretically, the operating frequency of radiator (f) can be calculated using (1).

$$f = \frac{c}{2L_{eff}\sqrt{\epsilon_r}} \tag{1}$$

where c, L_{eff} , and ϵ_r are the speed of light in vacuum, the length of microstrip patch radiator, and the relative permittivity of dielectric substrate used for the deployment. It clearly shows that the longer the patch leads the lower the operating frequency. This also applies for the relative permittivity value of dielectric substrate. Therefore, to reduce the length of microstrip patch radiator, a high relative permittivity of dielectric substrate is proposed for the realization. Here, an FR4 Epoxy dielectric substrate which has relative permittivity of 4.4 is employed in the implementation. Whilst to suit the required size of patch deployment, a spiral shape of patch is applied for the solution.

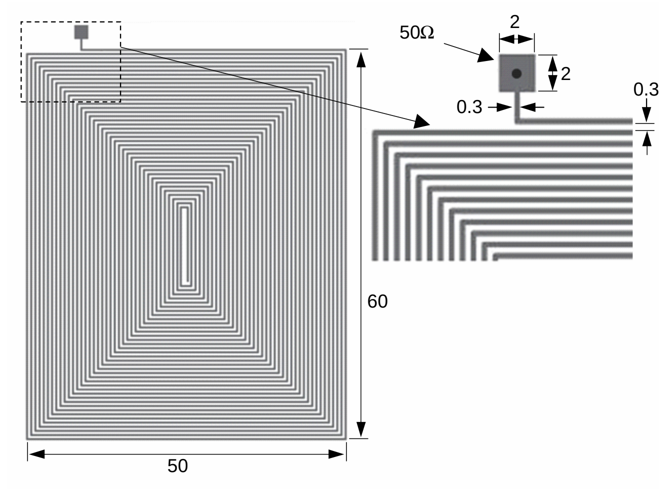

Fig. 1. Structure of microstrip patch radiator and its geometry (unit in mm)

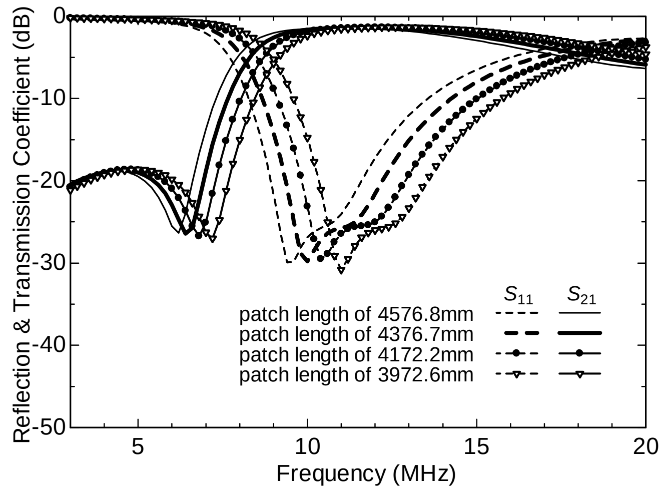

Fig. 2. Effects of varied microstrip patch length for radiator characteristic

In order the microstrip patch radiator can properly resonate around frequency of 10MHz, the length of microstrip patch radiator is investigated numerically. The patch of radiator which is made of metal copper with the thickness of 0.035mm is deployed on a grounded FR4 Epoxy dielectric substrate with the thickness of 0.8mm. The width of microstrip patch is set to be 0.3mm since it can provide a wide strip length of most major patches. While the distance between patches in the turns which is the same as width of microstrip patch, i.e. 0.3mm, is chosen to achieve the greatest long-patch. Furthermore, the thickness of dielectric substrate, i.e. 0.8mm, is expected to contribute a reasonable thickness for the radiator. Fig. 1 shows the proposed structure of microstrip patch radiator and its geometry in detail.

For the characterization purpose, SMA connectors which have characteristic impedances of 50Ω are connected at the input and output ports of radiator. As the radiator is developed from microstrip line, the characteristics of microstrip line consequently affect the characteristic of radiator as well. According to those reasons, therefore, some investigations of radiator characteristic as variation of patch length and of gap separation between 2 stacked radiators are carried out numerically to analyze the performance of proposed microstrip patch radiator.

III. Numerical Characterization and Discussion

In numerical characterization, S_{nn} represents the reflected power at n^{th} port of radiator, whereas S_{nm} represents the transmitted power from m^{th} port to n^{th} port. Here, Port#1 is set as the input port where the power comes into the microstrip patch radiator, and Port#2 acts as the output port where the power is obtained wirelessly from the microstrip patch radiator to be fed for the next circuit. In characterization process, if the value of S_{11} is very low and the value of S_{21} is close to 0dB, then it means the microstrip patch radiator performs appropriately and it is feedable for the next circuit. Therefore, the value of S_{11} and S_{21} will be key indicators in the evaluation of radiator performance.

To investigate the characteristic of radiator as variation of patch length to its operating frequency, the length of microstrip patch is varied into some different lengths. There are 4 variation lengths of microstrip patch applied for the investigation, those are 4576.8mm, 4376.7mm, 4172.2mm and 3972.6mm, while other parameters of radiator remain to the same. The characterization results for radiator with varied microstrip patch length is plotted in Fig. 2. Whereas the operating frequency and the value of S_{11} and S_{21} for each length are tabulated in Table I. It shows that the longer the microstrip patch, the operating frequency decreases which has been predicted by theoretical approach. Moreover, the values of S_{11} and S_{21} are uninfluenced remarkably by the variation of microstrip patch length. It seems that the value of S_{11} already exceeds the requirements which ranges between -29dB to -30dB, whereas the value of S_{21} is closed to 0dB in the range of -1.7dB to -1.5dB.

TABLE I. Summary of simulated results for radiator with varied microstrip patch length

Length (mm)	Operating frequency (MHz)	S_{11} (dB)	S_{21} (dB)
4576.8	9.4	-29.93	-1.73
4376.7	10	-29.79	-1.62
4172.2	10.4	-29.50	-1.63
3972.6	11	-30.80	-1.56

Next, the coupling between 2 stacked radiators is investigated by varying their gap separation. Basically, the closer separation between 2 radiators, the better performance occurs. This is affected by the flux generated by each microstrip patch which is stronger, producing the stronger coupling between the radiators so that the transferred power would be enlarged. However, there is another factor that should be considered, namely over coupling which happens on the radiator. Here, over coupling is defined as part of energy comes to a microstrip patch radiator which should be transferred, however, is dissipated back in an opposite direction, so that it can shift the operating frequency. If the gap separation between 2 radiators is very close, the coupling between radiators exceeds the limit of required coupling, referred as critical coupling, evoking the over coupling.

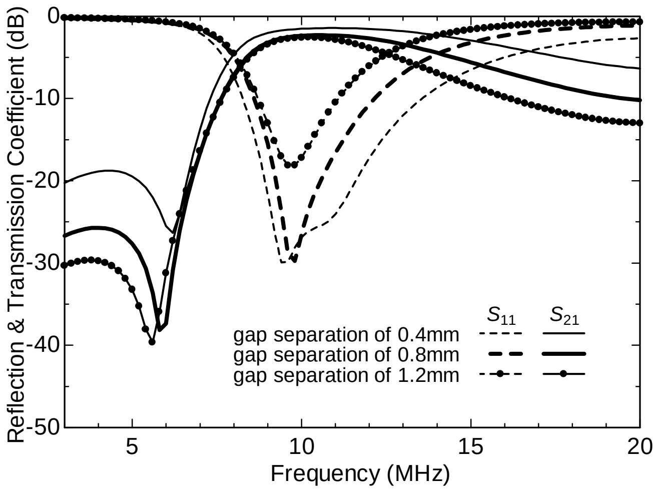

Fig. 3. Simulated results of varied gap separation between 2 stacked radiators

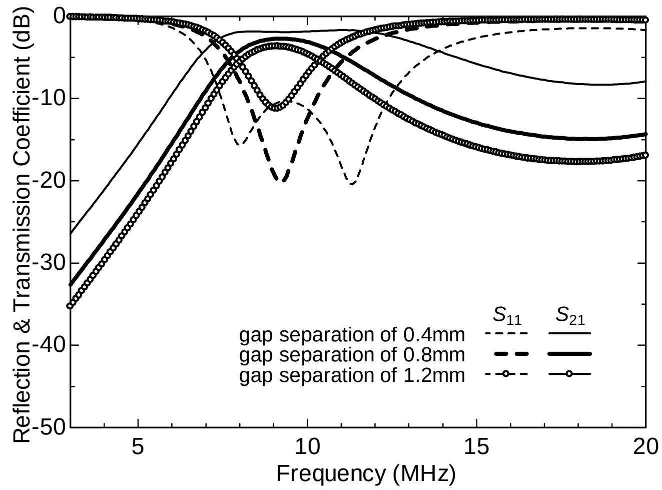

Fig. 5. Measured results of varied gap separation between 2 stacked radiators

In the investigation, there are 3 variations of gap separation between 2 stacked radiators, i.e. 0.4mm, 0.8mm, and 1.2mm. Fig. 3 plots characterization results obtained from the investigation. As the prediction, the closer separation between 2 radiators gives the better performance. This can be seen in the gap separation of 0.8mm where the value of S_{11} is to be smaller and the value of S_{21} is to be closer to 0dB. Moreover, the closer gap separation, the bandwidth also increases. However, at a very close gap separation, i.e. 0.4mm, other operating frequencies appear due to the over coupling between radiators. The values of S_{11} and S_{21} have already qualified with the limit values in successive ranges of -10.7dB to -30dB and of -3.7dB to -1.4dB.

IV. Fabrication and Experimental Characterization

After obtaining an optimum design of radiator and characterizing its properties, the radiator is realized through wet etching technique on an FR4 Epoxy dielectric substrate with the thickness of 0.8mm. Fig. 4 shows the pictures of fabricated radiators for experimental characterization. To investigate the effect of varied gap separation between 2 stacked radiators experimentally, 3 variations of gap separation, i.e. 0.4mm, 0.8mm, and 1.2mm, are examined in the characterization. Fig. 5 plots measured results of experimental characterization, whilst Table II summarizes the operating frequency and the value of S_{11} and S_{21} for each gap separation. It seems that the measured results shown in Fig. 5 have similar tendency as the numerical ones depicted in Fig. 3 in which the closer separation, i.e. 0.8mm, gives the better performance. The similarity is also seen in the over coupling which occurs for a very close gap separation between 2 stacked radiators, i.e. gap separation of 0.4mm.

Fig. 4. Pictures of fabricated radiators on FR4 Epoxy dielectric substrate

TABLE II. Summary of Measured Results for Radiator with Varied Gap Separation

Gap separation (mm)	Operating frequency (MHz)	S_{11} (dB)	S_{21} (dB)
0.4	11.33	-20.46	-1.70
0.8	9.21	-20.22	-2.72
1.2	9.21	-11.08	-3.68

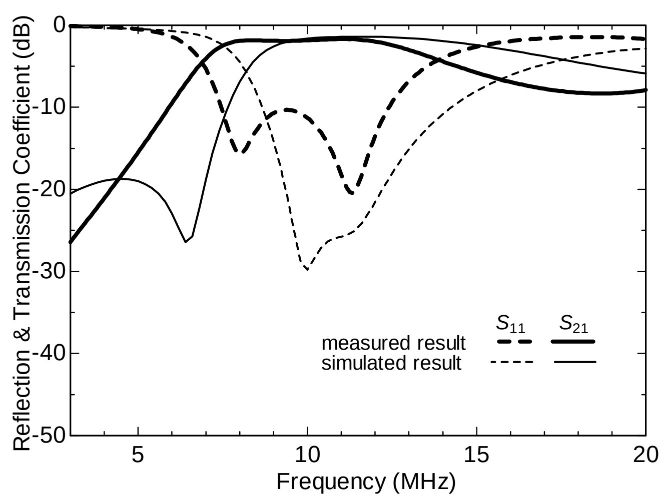

Fig. 6. Comparison of measured and simulated results for 0.4mm gap separation

Figs. 6–8 plot the comparison of results between experimental and numerical characterizations for the gap separation of 0.4mm, 0.8mm, and 1.2mm, respectively. Although the different values of S_{11} and S_{21} occur in the results for all gap separations, however their curves have a good agreement each other qualitatively. The discrepancy is possibly evoked by the different value of relative permittivity of FR4 Epoxy dielectric substrate set in the numerical characterization and used for the experimental characterization. Nevertheless, as long as the radiator still has small values of S_{11}, S_{21} close to 0dB and operating frequency around 10MHz, it can be said that the proposed radiator is implementable for wireless charging application as it has acceptable performance.

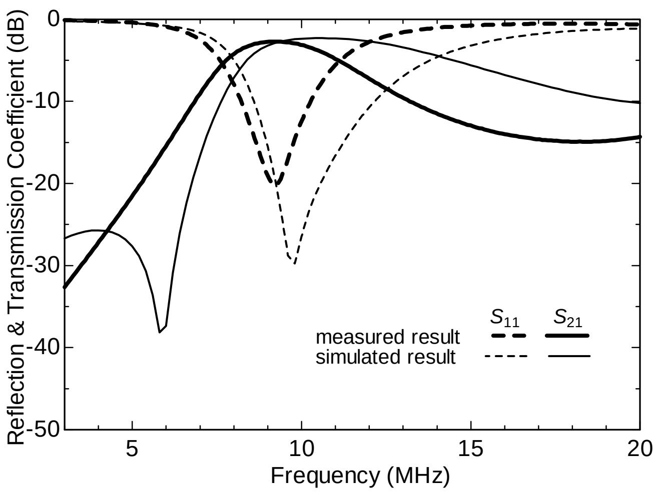

Fig. 7. Comparison of measured and simulated results for 0.8mm gap separation

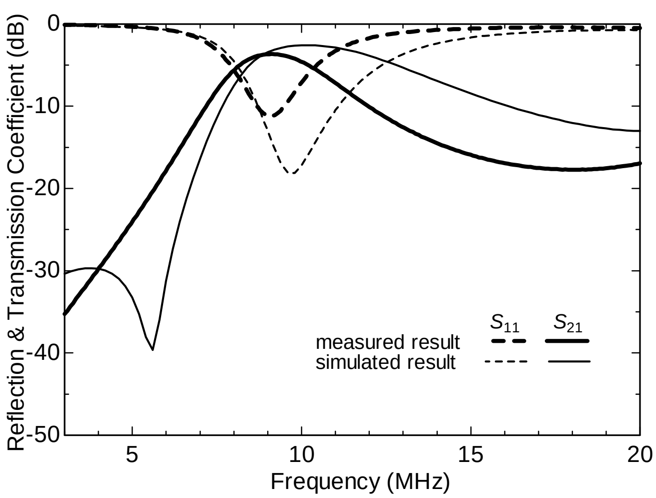

Fig. 8. Comparison of measured and simulated results for 1.2mm gap separation

V. CONCLUSION

The design and characterization of radiator for wireless charging application have been presented numerically and experimentally. It has been shown that the radiator was successfully designed based on electromagnetic coupling resonant using microstrip patch in a spiral shape. The radiator has been realized on a 0.8mm thick grounded FR4 Epoxy dielectric substrate with its dimension of 50mm $\times$ 70mm. Whereas the dimension of patch deployment was 50mm $\times$ 60mm with the total length of microstrip patch of 4376.7mm and the thickness of 0.035mm. The characteristics of radiator such as operating frequency, S_{11}, and S_{21} have been analyzed to obtain an optimum performance of radiator. From numerical characterization, the radiator has shown operating frequency, values of S_{11} and S_{21} of 10MHz, -29.79dB, and -1.62dB, respectively. Meanwhile from experimental characterization, the fabricated radiator has demonstrated operating frequency, values of S_{11} and S_{21} of 9.21MHz, -20.22dB, -2.72dB, respectively. In fact, there were some differences found between the numerical and experimental results for characterization of varied gap separation between 2 stacked radiator which is possibly due to the different value of relative permittivity of dielectric substrate used in the design and fabrication. In spite of discrepancies occurred in the numerical and experimental characterizations, it could be concluded that the realized radiator has had an acceptable performance for proposed application. In addition, the integration of radiator with transmitter and/or receiver in establishing a complete wireless charging system for mobile device is now in progress where the interesting result will be reported later.

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