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Investigation of Receiving Antenna for Energy Scavenging From Microwave Signal

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ABSTRACT

A novel high gain 2x2 array antenna operates at 2.45GHz for the RF (Radio Frequency) energy scavenging application is proposed and investigated. The antenna array consists of four rectangular patch antenna element fabricated on FR-4 substrate with air gap to ground plane using CST software. By adjusting the thickness of air gap and geometry of antenna array, the maximum gain and return loss can be achieved. The gain of simulated antenna array is about 14 dB and the return loss is more than -10dB.

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INTRODUCTION

G.A Deschamps indicates that the microstrip antenna has been widely used because it has several advantages over conventional microwave antenna (Deschamps, 1953). It isused widely for several reasons due to its low profile, lightweight, and low cost (James and Hall, 1989). However, the microstrip antenna has a weakness caused by low gain, low efficiencyand power handling capability (Zakaria *et al*., 2014). In this paper, the high gain antenna array using 2x2 rectangular patch and excited with probe-feeding is proposed and applied for energy scavenging.

FR-4 substrate for microstrip antenna is widely used in communication systems including WLAN, global system for mobile communications (GSM), radio frequency identification (RFID) and others. Recently, various types of antennas with WLAN systems have been widely used (Hwang and Pu, 2007). In general, both of electrical performance requirements and conditions of the external environment is very critical access point. Factor is important to point out the communication antenna access point, compact, high gain and narrow beam widths in both preferred plane.

MATERIALS AND METHODS

A microstrip rectangular 2x2 patch Array antenna with air gap is chosen due to aptitude of producing a 2.45GHz frequency. Computer Simulation Tool 2011(CST 2011) is used to design this antenna. The physical dimension of radiating antenna is 200x220mm^2. The radiating patch antenna array with 2x2 element distribute on the FR-4 substrate is 160x180mm^2. The patch array antenna and air gap technique are also increasing the gain and return loss (RL) of the antenna. In Table 1, it demonstrates specifications of the antenna.

Microstrip Patch Array Antenna Design:

In order to design microstrip patch rectangle antenna, it is needed to define the dimensions of the patch which are the width (W) and length (L) as indicated below (Wahab *et al*., 2010):

$$W = \frac{c}{2f}\sqrt{\frac{2}{\varepsilon r+1}} \qquad (1)$$

$$L = \frac{1}{2f\sqrt{\mu r\ \varepsilon r}\sqrt{\varepsilon\ eff}} \qquad (2)$$

Where,

$$\varepsilon\ eff = \frac{\varepsilon r+1}{2} + \frac{\varepsilon r-1}{2}[1+12\frac{h}{W}]^{-\frac{1}{2}} \qquad (3)$$

And,

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon\ eff+0.3)\left(\frac{W}{h}+0.264\right)}{(\varepsilon\ eff-0.3)\left(\frac{W}{h}+0.8\right)} \qquad (4)$$

Where f is center frequency and ε_{eff} is efficient permeability. The extended incremental length of the patch (L) can be calculated using Eq. 4. Where h is the thickness of the substrate.

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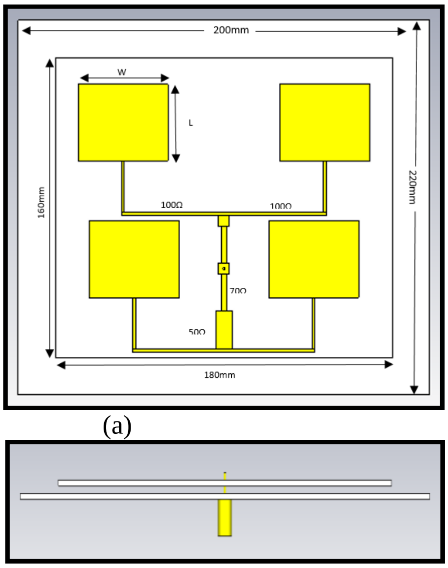
On the other hands, the antenna array consists of a network of two-way power divider branch. Transformer Quarter-wave (70 Ω) is used to match the 100 Ω to 50 Ω line.

Table 1: Design specifications.

Centre Frequency, f_o.	2.45GHz
Substrate	FR-4
Dielectric Constant of FR-4	4.4
Dielectric Constant of Air	1
Thickness of substrate	1.6mm
Loss Tangent	0.019
Thickness of Copper	0.035mm



(a)

(b)

Fig. 1: 2x2 Array Patch Antenna Structure (a) Front View, (b) Bottom View.

The impedance of quarter-wave transformer is:

$$Z1 = \sqrt{Zo\ x\ Rin} \quad (5)$$

Where R_{in} is,

$$Rin = \frac{1}{2Ge} \quad (6)$$

And,

$$Ge = \frac{0.00836\ W}{\lambda o} \quad (7)$$

Where Z_1 is the transformer characteristic impedance and Zo is the real characteristic impedance of the input transmission line (50Ω). Rin and Ge is the edge resistance at resonance and edge conductance. To find the width and length of the quarter-wave transformer and 50Ω feed-line, it is required to follow these conditions as shown below (Wahab *et al.*, 2010):

For condition when, $\frac{W}{h} > 2$

$$\frac{W}{h} = \frac{8e^{A}}{e^{2A}-2} \quad (8)$$

For condition when, $\frac{W}{h} < 2$

$$\frac{W}{h} = \frac{2}{\pi}[B - 1 - \ln(2B - 1)] + \frac{\varepsilon r - 1}{2\varepsilon r}\left[\ln(B - 1) + 0.39 - \left(\frac{0.61}{\varepsilon r}\right)\right] \quad (9)$$

Where h is the substrate. ForA and B, they can be found using these formulas:

$$A = \frac{Zo}{60}\left[\frac{\varepsilon r + 1}{2}\right]^{\frac{1}{2}} + \left[\frac{\varepsilon r - 1}{(\varepsilon r + 1)\left(0.23 + \left(\frac{0.11}{\varepsilon r}\right)\right)}\right] \quad (10)$$

$$B = \frac{377\pi}{2Zo\sqrt{\varepsilon r}} \quad (11)$$

In spite of to match the 100Ω to 50Ω transmission lines, the calculation step is:

$$Z1 = \sqrt{50\ x\ 100}\ = 70\Omega$$

Where substitute Z_o = 50Ω and R_{in} = 100Ω in order to get the transformer characteristic impedance. By using Eq. 8, 9, and 10, all impedance dimensions for 50Ω feed-line, 70Ω quarter-wave transformer and 100Ω impedance line can be found.

RESULT AND DISCUSSION

A. *Return loss, Gain, and Bandwidth:*

The simulation of the antenna for S-parameters is implemented using Computer Simulation Tool 2011 (CST 2011). Table 2 illustrates the changes that can be occur when changing the height of the air gap between these two ranges of (2mm ≤ h2 ≤ 6mm). The IEEE standard is required to have a -10dB S-parameter magnitude for antenna (James and Hall, 1989). From Table 2, it can be observed that the 4mm air gap is the ideal and it has -24.536 return loss. This indicates the low return loss with the highest gain (14.16dB) which obtained through the modification of air gap. It is also has a bandwidth of 87.1MHz for center frequency of 2.45GHz.However, Fig. 2 demonstrates the Return Loss graph for air gap at height of 4mm.

Table 2: Frequency, Return loss, Gain and Bandwidth with parameters of air gap height.

Air Gap (mm)	Frequency (GHz)	Return Loss (dB)	Gain (dB)	Bandwidth (MHz)
2	2.294	-15.525	13.81	59.9
3	2.394	-20.472	14.13	79.8
4	2.45	-24.536	14.16	87.1
5	2.482	-18.22	14.08	88.6
6	2.498	-15.245	13.94	85.7

Fig. 3 illustrates the Return Loss graph for a microstrip rectangular patch 2x2 Array antenna with air gap. Return loss graph at the height of 2mm is -15.525 dB but for 3mm, 4mm, 5mm, and 6mm height, the return loss are -20.472 dB, -24.536 dB, -18.220 dB, and -15.245dB respectively.

As a result, themodificationof airgapbetween thetwosubstrate are affected by modification inreturnlossandgain. However, the modification in the height ofair gapisinfluenced bythesizeof thesubstrateonantenna.

Fig. 5 shows the radiation pattern for air gap at height of 4mm. It demonstratesthat theantennaradiatesmore powerin thered(z-axis) fromthe other direction. Relating to 10dBreturn lossat2.45GHzband, the impedancebandwidthofthe antennanetworkfrom 2.4037 GHz to 2.4908 GHz withfraction bandwidth (FBW = $(f_H - f_L)/f_o = 3.5\%$).

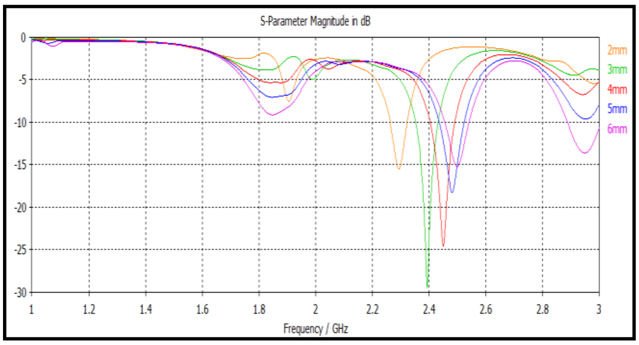


Fig. 2: Simulated result of Return loss for changing the height of air gap.

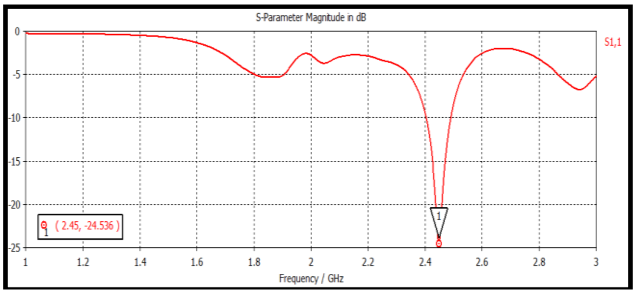
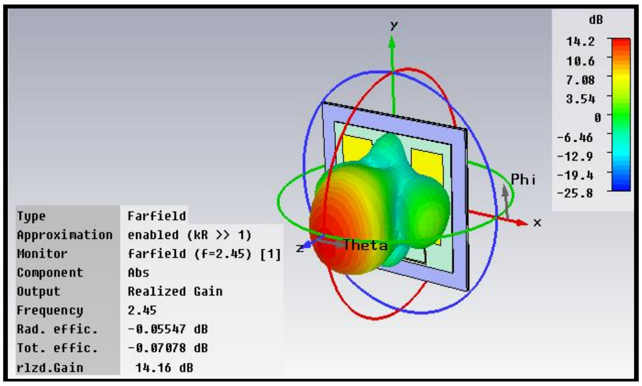


Fig. 3: Return Loss graph for air gap at height of 4mm.



```
Type            Farfield
Approximation   enabled (kR >> 1)
Monitor         farfield (f=2.45) [1]
Component       Abs
Output          Realized Gain
Frequency       2.45
Rad. effic.     -0.05547 dB
Tot. effic.     -0.07078 dB
rlzd.Gain        14.16 dB
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Fig. 4: Radiation pattern for air gap at height of 4mm.

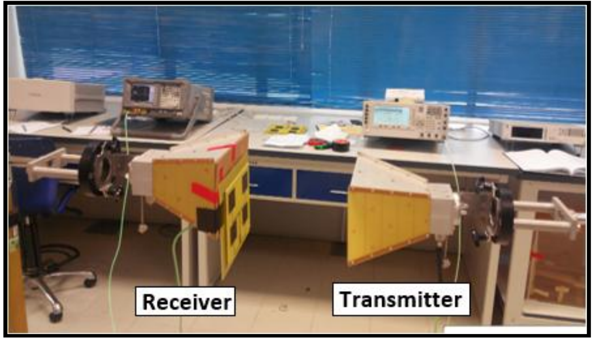

Fig. 5: Experimentstransmitpowerandreceiverpowerunder test.

B. *Power transmit and power receive:*

In Fig. 5, the experiment between the horn antenna as the transmitter antenna and the 2x2 array antenna as a receiver are performed.

The horn antenna is connected with signal generator to inject a certain amount of input power transmit range -20 dBm up to 20 dBm. The receiver antenna is connected to the spectrum analyzer to observe the output power and current in Watt, dBm, Volt, and Ampere. Table 3 to table 6 demonstrate the result of the experiment for the output power received by the antenna at certain length of distance. However, Table 7 shows the output voltage when the 2x2 array antenna is connected with the rectifier. The highest voltage output can be found is 3.94V at distance of 25cm and the power transmit is 20 dBm.

Table 3: Output power receiver at distance of 25cm.

Power Transmit (dBm)	Output Power (mW)	Output Power (dBm)	Current (μA)
-20	316.7 n	-34.99	77.46 μ
-10	2.609 μ	-25.69	228.4 μ
-5	7.788 μ	-21.09	393.6 μ
0	24.05 μ	-16.23	693.6 μ
5	74.63 μ	-11.26	1.222 m
10	230.7 μ	-6.396	2.148 m
15	730.1 μ	-1.364	3.821 m
20	1.549 m	1.901	5.566 m

Table 4: Output power receiver at distance of 50cm.

Power Transmit (dBm)	Output Power (Watt)	Output Power (dBm)	Current (A)
-20	148.1 n	-38.16	58 μ
-10	1.202 μ	-29.33	151.9 μ
-5	3.506 μ	-24.58	264.1 μ
0	10.8 μ	-19.69	463.5 μ
5	33.45 μ	-14.7	815.3 m
10	99.95 μ	-9.919	1.415 m
15	289.4 μ	-5.376	2.408 m
20	639.4	-1.942	3.591 m

Table 5: Output power receiver at distance of 75cm.

Power Transmit (dBm)	Output Power (Watt)	Output Power (dBm)	Current (A)
-20	77.43 n	-41.19	39.35 μ
-10	546 n	-32.63	104.5 μ
-5	1.573 μ	-28.03	177.4 μ
0	5.6766 μ	-22.39	342.56 μ
5	17.96 μ	-17.46	599.4 μ
10	54.39 μ	-12.65	1.045 m
15	166.6 μ	-7.782	1.822 m
20	344.7 μ	-4.625	2.626 m

Table 6: Output power receiver at distance of 100cm.

Power Transmit (dBm)	Output Power (Watt)	Output Power (dBm)	Current (A)
-20	49.56 n	-41.19	38.26 μ
-10	312.22 n	-34.62	81.33 μ
-5	1.066 μ	-28.34	143.76 μ
0	5.3422 μ	-23.55	235.25 μ
5	10.225 μ	-18.64	412.5 μ

10	30.85 μ	-14.22	751.11 μ
15	95.6 μ	-9.2	1.32 m
20	188.2 μ	-6.775	1.55 m

Table 7: Output voltage at certain length of distance.

Input Power (dBm)	Receive Antenna (Output Voltage)			
	D=25cm	D=50cm	D=75cm	D=100cm
-20	0.00	0.00	0.00	0.00
-10	0.01	0.00	0.00	0.00
-5	0.09	0.02	0.00	0.00
0	0.27	0.11	0.05	0.02
5	0.66	0.33	0.19	0.11
10	1.37	0.77	0.49	0.32
15	2.72	1.64	1.08	0.76
20	3.94	2.35	1.59	1.12

Conclusion:

A MicrostripRectangularPatch Antenna2x2Array with an air gaptoscavengingenergyapplicationsis successfully presented. The simulated 10dB return loss impedance bandwidth is around 3.5%. The gain of simulated antenna array is about 14dB. In experiment for power output, the distance can affect the power received in term of voltage output, current output, and power output. However, when the power is increased, the distance for power transmit and the receiver will be increased as well. The proposed novel high gain 2x2 array microstrip patch antenna is a preferable choice for the RF energy scavenging applications.

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