Rectangular Microstrip Patch Antenna Based on Resonant Circuit Approach

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***Abstract*—This paper presents the investigation based upon the resonant circuit approach to characterize the rectangular microstrip patch antenna from the low-pass prototype lumped element. The physical layout of the rectangular microstrip patch antenna based on single-mode and dual-mode will be established. An improvement on bandwidth of the antenna can be achieved by increasing the number of modes. In the paper, the understanding of microwave filter synthesis technique is applied in order to obtain the resonance at 2 GHz. A notch technique is used in the design to produce dual-mode frequencies on the microstrip patch antenna. The prototype circuit and proposed physical layout of the single and dual-mode microstrip patch antennas are demonstrated through the analysis of circuit and EM simulations in order to proof the proposed concept. This study would be useful to realize antenna for broadband applications as well as to investigate the appropriate technique for integrating antenna and microwave filter.**

Keywords-Rectangular microstrip patch antenna; Single-mode Antenna; Dual-mode Antenna; Microwave Filter.

I. INTRODUCTION

The rapid development of wireless applications ranging from Bluetooth, WLANs, GSM, LTE, satellite and military applications requires more efficient, low profile and flexible antennas. Microstrip patch antennas are generally used in communication systems for their benefit of ease of fabrication, low profile, lighter in weight and low cost [1]. However, there is a limitation on its performance for a microstrip patch antenna in term of narrow bandwidth [1][2]. The most well-known method was proposed to overcome the limitation is by increasing the height of the substrate [3]. However, this method increases the complexity and suffers from the power loss. In [4], the antenna was designed with modified circle-like slot was used on the elements. However, etching two L-shaped slots on the ground are slightly complex to design on the antenna especially come to 50 Ω impedance matching.

In this paper, a development of the rectangular microstrip patch antenna based on microwave filter circuit theory is presented. The rectangular microstrip patch antennas are designed at resonant frequency of 2 GHz for single and dual-mode. The advantages of this technique are the realization of microstrip patch antenna that can be transformed for broadband applications and also can be applied to the integration technique between antenna and microwave filter.

II. EQUIVALENT CIRCUIT DESIGN

In this section, a low-pass filter prototype equivalent circuit is used to produce single-mode antenna equivalent circuit as shown in Fig. 1. The inverter, K_{01} represents the coupling mechanism between the input port and the resonance circuit [5]. In Fig 2 (a) shows the equivalent circuit of single-mode based on the low-pass prototype circuit shown in Fig. 1. Similarly the dual-mode antenna equivalent circuit as shown in Fig. 2 (b) can be developed based on the second order of the low-pass prototype circuit. The dual-mode antenna equivalent circuit can also be developed based on a combination of two single-mode equivalent circuit.

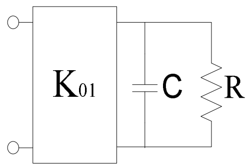

Figure 1. Low-pass equivalent circuit of rectangular microstrip patch antenna

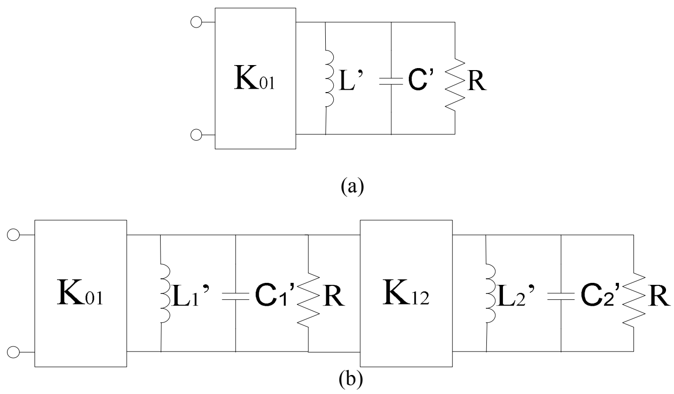

Figure 2. (a) Single-mode circuit of the rectangular microstrip patch antenna (b) Dual-mode circuit of the rectangular microstrip patch antenna

The impedance inverter $K_{r,\,r+1}$ and the capacitance C_r value of the low-pass prototype can be determined using [6]:

$$C_r = \frac{2}{\eta}\sin\left[\frac{(2r-1)\pi}{2N}\right] \quad (1)$$

$$K_{r,r+1} = \frac{\left[\eta^2 + sin^2(r\pi/N)\right]^{1/2}}{\eta} \quad (2)$$

where *N,* is the number of order of the network and η, is defined as [6]:

$$\eta = sinh\left[\frac{1}{N} sinh^{-1}\left(\frac{1}{\epsilon}\right)\right] \quad (3)$$

while ϵ is the ripple of insertion loss. The antenna equivalent circuit can be transformed from the low-pass prototype equivalent circuit using [6]:

$$L'_r = \frac{1}{\alpha C_r \omega_o} \quad (4)$$

$$C'_r = \frac{\alpha C_r}{\omega_0} \quad (5)$$

where ω_o is the geometric midband frequency; α is the bandwidth scaling factor and the *r* is the number of order. The resistances, R acts as load of the prototype circuit.

III. Rectangular Microstrip Patch Antenna

The transformation from the antenna equivalent circuit to physical realization is implemented using rectangular microstrip patch antenna technology. The dimensions of the rectangular microstrip patch antenna can determined by the width, *w,* and the length, *L*, as shown in Fig. 3, using [7]:

$$w = \frac{c}{2f_c}\sqrt{\frac{2}{\varepsilon_r+1}} \quad (6)$$

$$L = \frac{1}{2f_c\sqrt{\varepsilon_{eff}}\sqrt{\mu_r\varepsilon_r}} \quad (7)$$

where f_c is center frequency and ε_{eff} is the efficient permeability. ΔL extended incremental length of the patch can be calculated using the equation below [7]:

$$\frac{\Delta L}{h} = 0.412\frac{(\varepsilon_{eff}+0.3)\left(\frac{w}{h}+0.264\right)}{(\varepsilon_{eff}-0.258)\left(\frac{w}{h}+0.8\right)} \quad (8)$$

h is the thickness of the dielectric substrate and y_o can be calculated using this formula [7]:

$$y_o = \frac{L}{\pi}cos^{-1}\left[\frac{150}{R}\right]^{1/2} \quad (9)$$

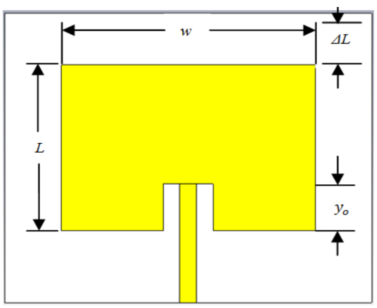

Figure 3. Top view rectangular microstrip patch antenna

where R is the impedance and y_o is the inset feed line as shown in Fig. 3. The dual-mode frequency of rectangular microstrip patch antenna is realized by simply introducing a notch concept that will be explained in next section.

IV. Simulation Results

A. Single mode

In this section, the single-mode antenna equivalent circuit has been designed at 2 GHz using equations (1) – (5) to obtain the coupling value, K_{01} of 50, capacitance, L' = 98.98 pF and inductance, C' = 63.98 pH.

Fig. 4 shows the simulated results of the antenna equivalent circuit. It shows that the return loss, S_{11}, with better than -30 dB and a -10 dB bandwidth of around 31 MHz have been achieved.

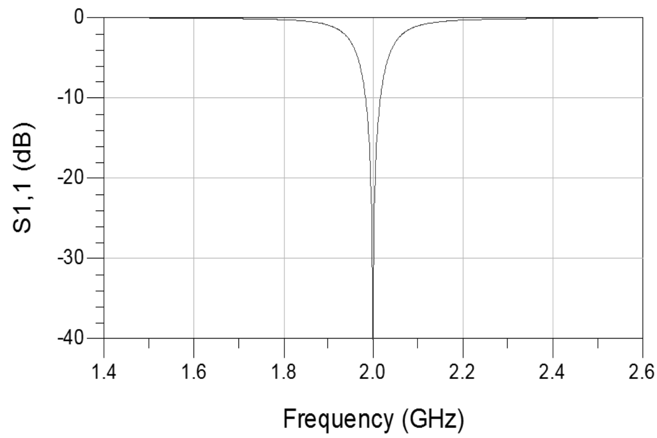

Figure 4. Simulation results of equivalent ideal circuit antenna for single-mode

The antenna equivalent circuit and the physical layout have been simulated using Advanced Design System (ADS) and CST Microwave Studio in order to validate the proposed concept. The device is constructed using FR-4 on a 1.6 mm dielectric substrate thick with permeability constant ε_r = 4.6. The thickness of copper is 0.035 mm and the loss tangent is 0.019. The dimension of the rectangular microstrip patch antenna can be determined using equations (6) – (9). Thus, the length, *L*, and width, *w*, of the patch antenna are 32.4 mm and 48.79 mm respectively. The antenna is connected to input port with 50 Ω feed line.

Fig. 5 shows the effect on the resonant frequency by varying the length, *L*, of the microstrip patch antenna based on EM simulations using CST. It shows that the length of 32.7184 mm gives good response on the return loss at resonance of 2 GHz. This is summarized in Table I. It indicates that at 2 GHz the return loss has achieved -30 dB with a -10 dB bandwidth approximately of 39.9 MHz has been obtained.

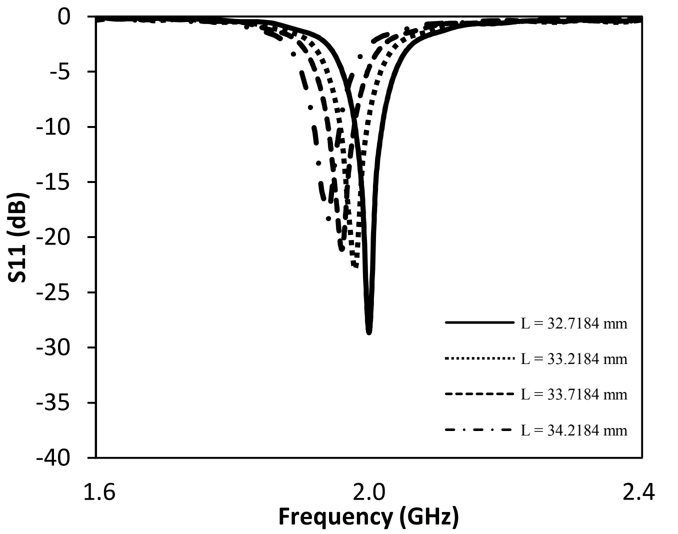

Figure 5. EM Simulation results of microstrip patch antenna for single-mode

TABLE I. SIMULATION RESULTS FOR SINGLE-MODE RECTANGULAR MICROSTRIP PATCH ANTENNA

Frequency (GHz)	**Return loss (dB)**	**Length, *L* (mm)**	**Bandwidth (MHz)**
1.937	-19.12	34.2184	37.14
1.958	-21.38	33.7184	38.57
1.987	-25.05	33.2184	40.19
2.000	-29.16	32.7184	39.90

B. Dual mode

Similarly for the dual-mode and using equations (1) – (5), the antenna equivalent circuit can be designed at 2 GHz with coupling values, K_{01} of 50, and K_{12} of 55.2765, while the capacitance, $C_1' = C_2' = 42.436$ pF and inductance, $L_1' = L_2' = 149.225$ pH. Fig. 6 shows the simulated results of the antenna equivalent circuit. It shows that the return loss, S_{11} with better than -12 dB and a -10 dB bandwidth of around 82 MHz have been achieved.

The antenna equivalent circuit and the physical layout have been simulated using Advanced Design System (ADS) and CST Microwave Studio in order to validate the proposed concept. The device is constructed using FR-4 on a 1.6mm dielectric substrate thick with permeability constant ε_r =4.6. The thickness of copper is 0.035mm and the loss tangent is 0.019. The dimension of the rectangular microstrip patch antenna can be determined using equations (6) – (9). Thus, the length, *L*, and width, *w*, of the patch antenna are 30.5 mm and 70.6 mm respectively. The antenna is connected to input port with 50 Ω feed line. The size of the notch to produce a dual - mode response is 18 mm x 2 mm is shown in Fig. 7. It is found that antenna having an appropriate size of notch resonates at two different frequencies but with improvement on the bandwidth as shown in Fig. 8.

Fig. 8 shows the effect on the resonant frequency by varying the length, *L*, of the microstrip patch antenna based on EM simulations using CST. It shows that the length, *L*, of 30.5 mm gives a good response to the return loss and resonances at 1.988 GHz and 2.023 GHz respectively. Table II summarizes the variations of length, *L*, with its response. It indicates that at center frequency of 2 GHz, the return loss, S_{11} with better than -23 dB and a -10dB bandwidth approximately of 76.87 MHz have been obtained.

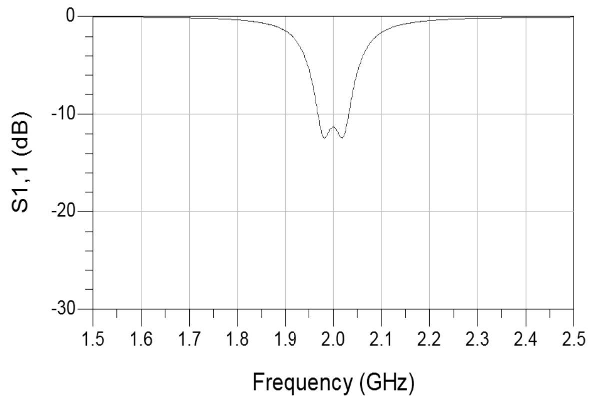

Figure 6. Simulation results of equivalent ideal circuit antenna for dual-mode

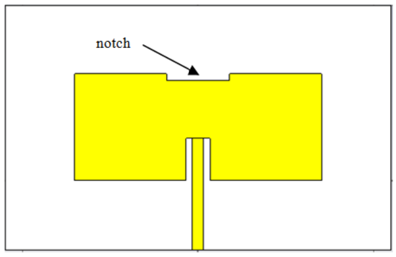

Figure 7. The physical layer of microstrip patch antenna with a notch for dual-mode

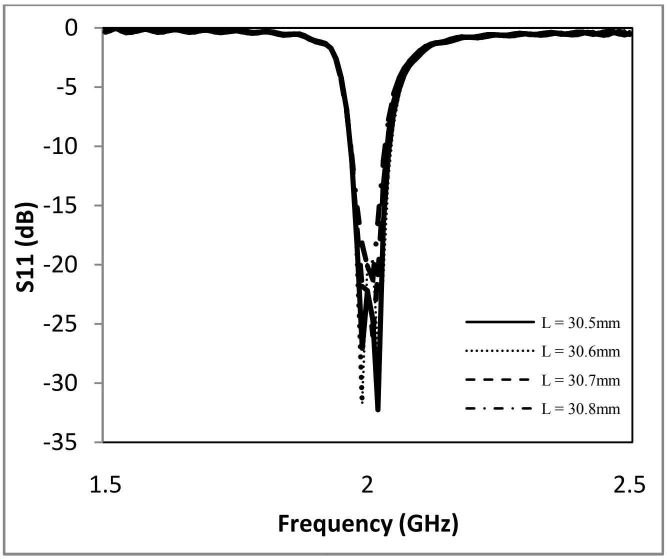

Figure 8. EM Simulation results of microstrip patch antenna for dual-mode

TABLE II. SIMULATION RESULTS FOR DUAL-MODE RECTANGULAR MICROSTRIP PATCH ANTENNA

Dual-Frequency (GHz)	Return loss (dB)	Length, *L* (mm)	Bandwidth (MHz)
1.988 & 2.023	-44.25 & -31.60	30.5	76.87
1.989 & 2.018	-27.23 & -42.01	30.6	73.24
1.990 & 2.012	-21.81 & -26.65	30.7	69.03
1.989 & 2.008	-18.04 & -21.41	30.8	64.53

Fig. 9 shows the radiation pattern for the single-mode antenna at 2 GHz. The pattern represents the main lobe magnitude of 4.9 dB at 2.0 degree direction from the origin point. While Fig. 10 shows the radiation pattern for the dual-mode antenna at the resonance of 2 GHz. The main lobe magnitude of 4.7 dB at 1.0 degree direction from the origin point can be observed.

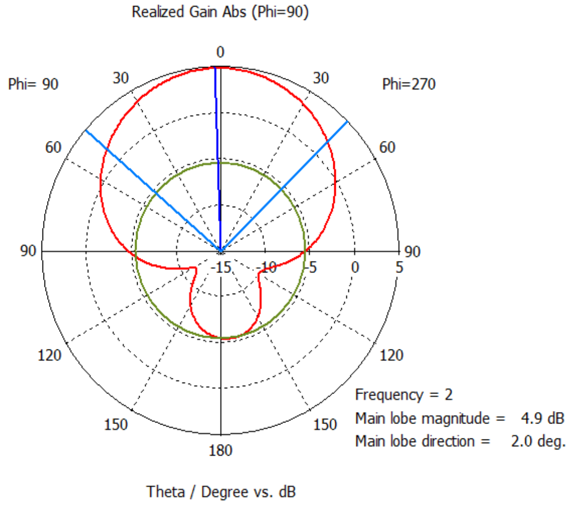

Figure 9. Simulated radiation pattern for single-mode at frequency 2 GHz

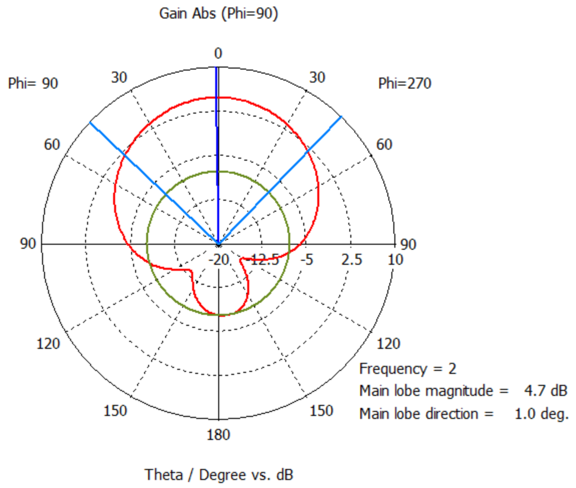

Figure 10. Simulated radiation pattern for dual-mode at center frequency 2.003 GHz

The comparison between single- and dual-mode antennas can be seen in Table III. It shows that the bandwidth of the microstrip patch antenna can be improved through dual-mode response. However further analysis and investigation on the fabrication of the single- and dual-mode antennas need to be carried out in future works.

TABLE III. COMPARISON RESULTS BETWEEN SINGLE-MODE AND DUAL-MODE FOR RECTANGULAR MICROSTRIP PATCH ANTENNA

	Single-Mode		Dual-mode	
	Prototype Circuit	Physical layout	Prototype Circuit	Physical layout
Center Frequency (GHz)	2.000	2.000	2.000	2.000
Return loss (dB)	-79.53	-29.16	- 12.1	- 23.5
-10 dB Bandwidth (MHz)	31	39.9	76.87	76.87

V. CONCLUSION

A new technique to produce dual-mode rectangular microstrip patch antenna based on resonant circuit approach has been developed. The EM simulated results show good agreements with the ideal circuit. The main advantage of this technique is the antenna can be systematically designed to improve the bandwidth of the response. This study is also useful for the design of broadband antenna applications as well as to realize integration between the antenna and microwave filter in a single device.

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REFERENCES

[1] Vishwakarma, R.K.; Kumar, R.; ,"Rectangular notch microstrip antenna for dual-band operation," *Recent Advances in Microwave Theory and Applications, 2008 International Conference on Microwave*, pp.675-677, 21-24 Nov. 2008.

[2] Chew, W.C.; Liu, Q.; , "Resonance frequency of a rectangular microstrip patch," *IEEE Transactions on Antennas and Propagation,* vol.36, no.8, pp.1045-1056, Aug 1988.

[3] Dubey, M.; Bharadwaj, D.; Saini, J.S.; Saxena, V.K.; Jain, R.; Bhatnagar, D.; , "Dual frequency rectangular patch antenna with a rectangular notch for improved bandwidth performance," *Recent Advances in Microwave Theory and Applications, 2008 International Conference on Microwave.*, pp.809-811, 21-24 Nov. 2008.

[4] Emadian, R.; Mirmozafari, M.; Ghobadi, C.; Nourinia, J.; , "Bandwidth enhancement of dual band-notched circle-like slot antenna," *Electronics Letters* , vol.48, no.7, pp.356-357, March 29 2012.

[5] Abunjaileh, A.I.; Hunter, I.C.; Kemp, A.H.; , "Application of dual-mode filter techniques to the broadband matching of microstrip patch antennas," Microwaves, Antennas & Propagation, IET , vol.1, no.2, pp.273-276, April 2007.

[6] Ian Hunter, Theory and Design of Microwave Filters, The Institution of Electrical Engineers, 2001.

[7] C. A. Balanis, Antenna Theory: Analysis and Design, 3rd edition, Wiley, 2005.