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Dual-band Filtenna Array for WLAN Applications

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Abstract: This paper presents the design and results of a dual-band antenna array integrated with bandpass filters for WLAN applications. The array is fed with a single 50 Ω port and consists of two radiating elements; thereby having a 1x2 array structure. The two bands of the antenna array correspond to the two WLAN bands of 2.4 GHz and 5.8 GHz. A standalone array has first been designed. Other than the two fundamental resonant frequencies, the standalone array exhibits spurious harmonics at various other frequencies. For the suppression of these harmonics, the array has been integrated with two bandpass filters, centered at 2.4 GHz and 5.8 GHz. The resulting filtenna array was simulated, fabricated and measured. Obtained simulation and measurement results agree well with each other and have been presented to validate the accuracy of the proposed structure. Measured return loss of the structure shows dual-bands at 2.4 GHz and 5.8 GHz of more than 30 dB each and also a successful suppression of the spurious harmonics of the antenna array has been achieved. Radiation patterns have also been simulated and measured and both results shown. The gain and efficiency have also been presented; with the values being 6.7 dBi and 70% for the 2.4 GHz band and 7.4 dBi and 81% for the 5.8 GHz band respectively.

Index Term— antenna arrays; bandpass filters; filtenna arrays; harmonic suppression; wlan.

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I. INTRODUCTION

An antenna is an integral part of all wireless communication devices. Antenna arrays are better than single antenna elements; primarily since they are more powerful with regards to transmitting and receiving signals, performing multiple tasks at the same time and also because they share the same feed network for the radiating elements, rather than having individual feed networks for multiple antennas. The WLAN operates at 2.4 GHz and 5.8 GHz as defined by the IEEE 802.11a/b/g/n/ac standards [1]. Currently, the 2.4 GHz and 5.8 GHz point-to-point antenna arrays are mounted separately with discrete ports [2]. It is difficult to achieve a broadband planar antenna array with stable directional radiation patterns from 2.0–6.0 GHz, as gain is proportional to the radiation aperture [2]. Hence, a dual-band array structure is preferred due to its simple system configuration and cost minimization. Although similar work has been proposed in [2] and [3], but is disadvantageous with respect to quite a number of factors; such as, larger 2x2 array structures, single-band operation, final response not being sufficiently sharp and most importantly spurious harmonics not being fully rejected. Similarly, [4] and [5] are unfavorable as well since the filters employed are of 3rd and 4th orders, and again the spurious harmonics have not been fully rejected. In this presented work, a dual-band 1x2 antenna array with 2nd order integrated filters has been designed, modelled, simulated and fabricated. Initially, a standalone array (array without filters) - fed by a single feed network - was designed and was shown to possess spurious harmonics in addition to the two main resonant frequencies. Therefore, bandpass filters were chosen to be integrated within the array. The filters would serve to allow the wanted frequencies to pass through, while rejecting all others. Hence, a full suppression of the spurious harmonics has been satisfactorily achieved. The designed antenna array utilizes microstrip technology. The organization of the paper is as follows: in section II, the designs of the individual components and the overall proposed structure are detailed. Section III presents the results and a comparison of this work with others listed in the references. The conclusions of the work follow in section IV.

II. DESIGN OF ANTENNA ARRAY, FILTERS AND THEIR INTEGRATION

The proposed standalone antenna array has been illustrated in Fig. 1. The array consists of two antenna elements, designed to have fundamental resonant frequencies at 2.4 GHz and 5.8 GHz by using the design equations given in [6]. The two elements are joined to 50 Ω transmission lines via $\lambda_g/4$ long transmission lines (quarter-wave transformers) of an impedance 76.71 Ω; where $\lambda_g/4$ is the guided wavelength at each element's respective resonant frequency. The whole structure is fed by means of a single 50 Ω port. The power from this port is split in to two branches through a transmission line of an impedance 76.71 Ω. The length of this power-splitting transmission line is dependent on the spacing between the two patch antennas. The two antenna elements are spaced at a distance of $0.5\lambda_g$ in order to minimize any mutual coupling that be present; where λ_g is the guided wavelength at the smaller operational frequency of 2.4 GHz. The two designed antenna elements are then connected to the two ends of the power-splitting line; thus forming a 1x2 antenna array.

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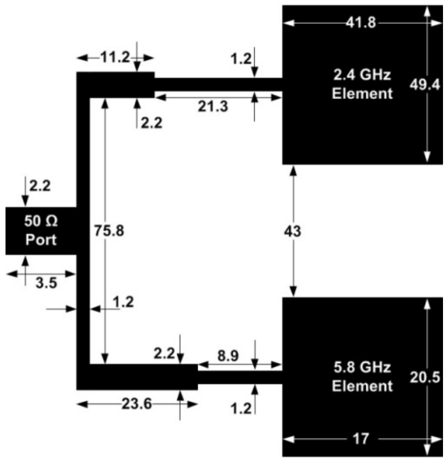

Figure 1 Geometry of antenna array (dimensions in mm).

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The bandpass filters have a pseudo-interdigital structural shape and are of second order each. Their basic design has been shown in Fig. 2. The values of the parameters in the figure have been provided in Table 1. The 5.8 GHz filter was chosen to have a narrow passband. This is advantageous because upon integration with the array, a sharp response and better rejection of the spurious harmonics would be achieved. Comparatively, the 2.4 GHz filter has a slightly wider passband than the 5.8 GHz filter. This is attained by using a smaller value for the widths of the interdigital fingers and less spacing between the fingers. This is done in order to achieve two things: to minimize any mutual coupling between the two filters when they will be connected to the same transmission feedline and to minimize the overall length of the entire structure.

Figure 2 Geometry of bandpass filters.

Parameters	2.4 GHz Filter	5.8 GHz Filter
	Value (mm)	*Value (mm)*
L1	3.5	3.5
L2	23.8	8.3
L3	1.5	3.4
W1	2.2	2.2
W2	0.3	0.6
G1	0.9	0.3
G2	0.3	0.8

Table 1 Dimensions of bandpass filters.

With the aim of forming an antenna array with integrated filters, i.e. filtenna array, for spurious harmonics rejection, the two designed bandpass filters are combined in the array next to the power-splitting line. The power-splitting transmission line acts as a feedline for both filters. Furthermore, since the integration of the bandpass filters causes the overall width of the structure to increase substantially, the distance between the two antenna elements is decreased from $0.5\lambda_g$ to $0.33\lambda_g$; where λ_g is the guided wavelength at 2.4 GHz. The ensuing final structure has been illustrated in Fig. 3. When the 50 Ω port of the resulting structure is excited, current flows in and then gets divided in to the two branches. Since the two branches are feedlines for the two filters, the current then flows in to the two filters through coupling. Each filter then lets pass through only its respective frequency, while rejecting all others. Lastly, the two patch antennas radiate at their particular resonant frequencies, which are the same frequencies passed out by the two bandpass filters.

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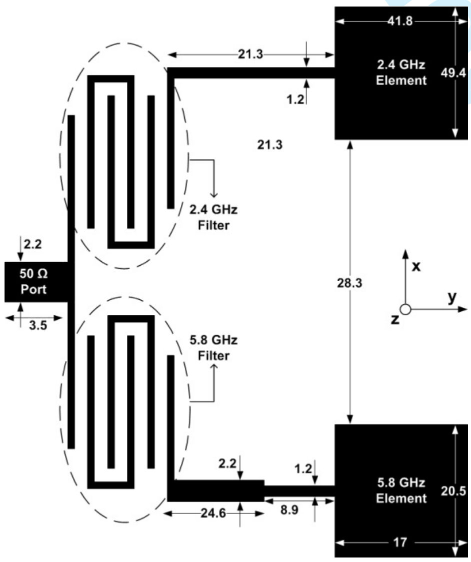

Figure 3 Geometry of filtenna array (dimensions in mm).

III. RESULTS

All the proposed structures have been designed on a Rogers RT5880 substrate of thickness 0.79 mm, having a dielectric permittivity $\varepsilon_r = 2.2$ and a dielectric loss tangent $\tan\delta = 0.0009$. They have been modelled and simulated using the commercial software *Sonnet*.

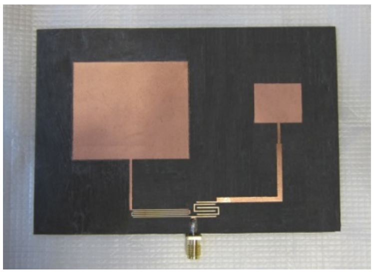

Figure 4 Photograph of the fabricated filtenna array.

A) S-parameters of Standalone Array

The S-parameters of the standalone array have been presented in Fig. 5. The dominant mode resonant frequencies, i.e. 2.4 GHz and 5.8 GHz, are at a return loss of almost 30 dB each. As can be also seen, other than the resonant frequencies, spurious harmonics are present at various other frequencies. These spurious harmonics interfere with the main signals: causing distortion as well as loss of sensitivity in the main signals.

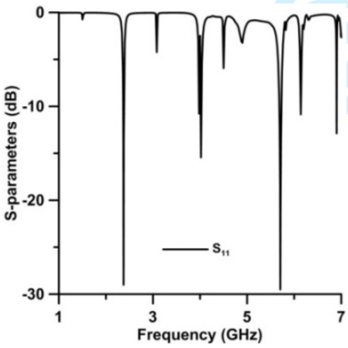

Figure 5 S-parameters of standalone antenna array.

B) S-parameters of Bandpass Filters

The simulated S-parameters of the bandpass filters presented in Fig. 6 (a) and (b) show that the filters are centred at 2.4 GHz and 5.8 GHz respectively. The results also show the filters' 3 dB passband to be 2.08–2.69 GHz and 5.51–6.11 GHz and hence have fractional

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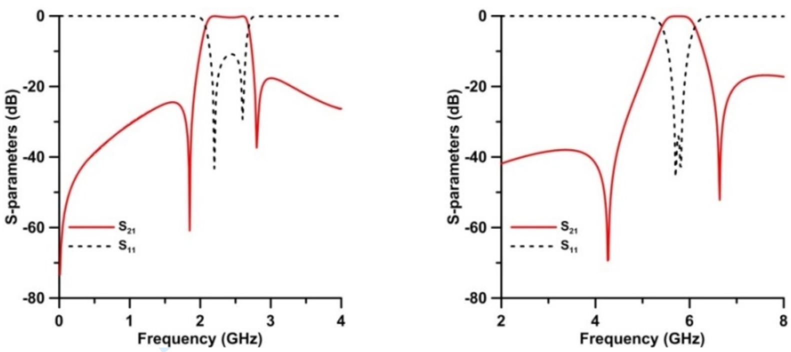
bandwidths of 25.4 % and 10.4 % respectively. The simulation results show the insertion loss to be about 0.1 dB in the both passbands. Transmission zeroes appear at frequencies below and above the passbands of both filters. The transmission zeroes improve near-bandwidth rejection. The return loss is more than 13 dB for most of the passband bandwidth in both filters; indicating that a good matching is present within each filter.



(a) **(b)**

Figure 6 S-parameters of (a) 2.4 GHz bandpass filter and (b) 5.8 GHz bandpass filter.

C) S-parameters of Filtenna Array

The simulation result of the filtenna array has been shown in Fig. 7. The result shows the proposed structure exhibiting dual-band fundamental resonant frequencies and a major suppression of the spurious harmonics has been achieved, as desired. However, the pick at 4.5 GHz has not been fully rejected. This can be resolved by shifting forwards the first transmission zero of the 5.8 GHz filter. Although the essential results have been obtained in terms of spurious harmonics suppression, the return loss of the antenna array at the two dominant resonant frequencies has decreased by about 7 dB each, i.e. resulting at about 23 dB. This can be attributed to the extra metallization of the integrated filters and extra couplings involved in the new structure. The fabricated filtenna array was measured using an Agilent E8361A PNA Network Analyzer. The measured result has also been presented in Fig. 7. As can been seen, an excellent match between the simulation and the measurement results has been obtained. The frequencies shift in the fabricated circuit is negligible. Furthermore, the measured S-parameters are substantially better than the simulated ones; with 35 dB at 2.4 GHz and almost 30 dB at 5.8 GHz. Measurement result also matches the simulation result with regards to the suppression of spurious harmonics. Measured result shows slight fluctuations in the band, with all spurious harmonics measured at a return loss of less than 1.75 dB, including the pick at 4.5 GHz.

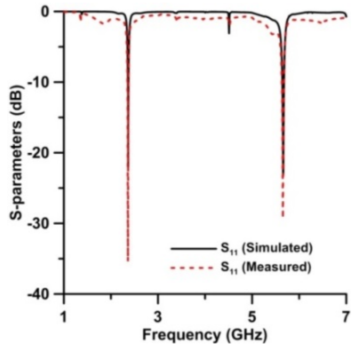
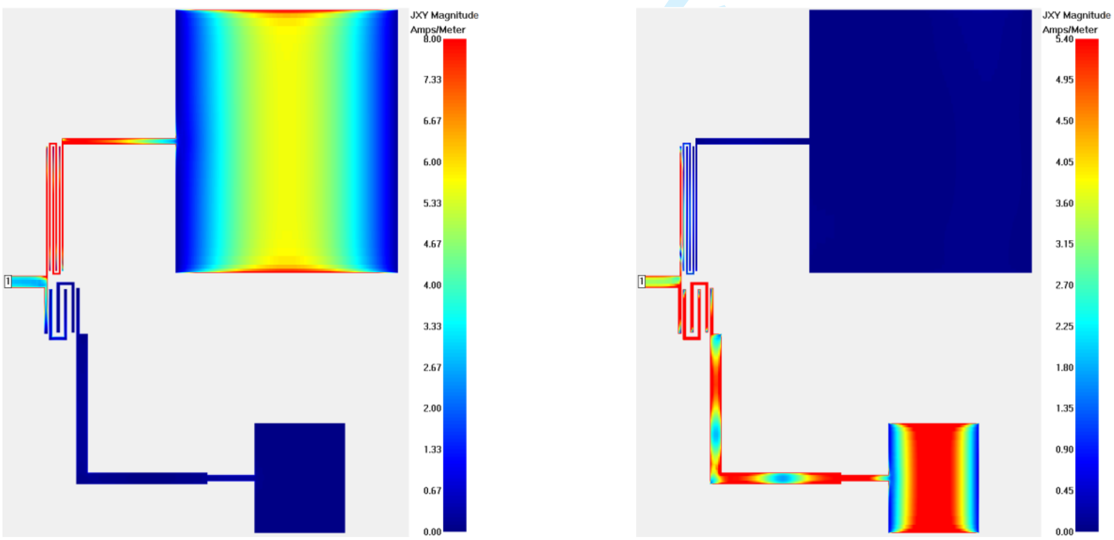


Figure 7 S-parameters of filtenna array.

D) Surface Current Distribution of Filtenna Array

Fig. 8 (a) and (b) show the simulated surface current distribution results of the structure at 2.4 GHz and 5.8 GHz respectively. Two observations can be made from these results. Firstly, maximum current is concentrated in each element at its respective frequency, while no current is present in the other element at the same time. Secondly, at the corresponding frequency of each bandpass filer and antenna element, there seems to be negligible mutual coupling present in the other bandpass filter or the antenna element at the same time.

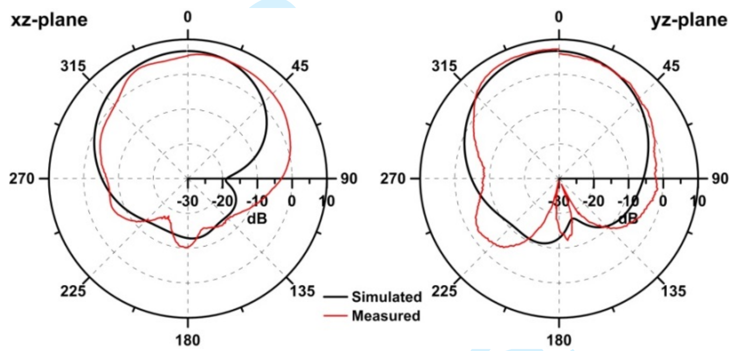


(a) **(b)**

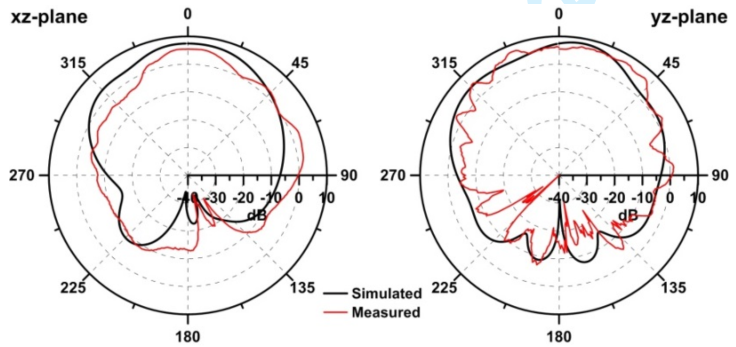
Figure 8 Surface current distribution at (a) 2.4 GHz and (b) 5.8 GHz.

E) Radiation Patterns, Gain and Efficiency of Filtenna Array

The radiation patterns of the filtenna array were simulated as well as measured in the xz-plane and yz-plane; with the results being shown in Fig. 9. The simulation and measurements results agree well with each other. As seen from the two figures, at both frequencies in both planes, maximum radiation appears to be at the top of each antenna element, i.e. when θ = 0°. Whereas, between θ = 90°–270° the radiation appears to start decreasing; with the least being when nearing the bottom of the structure, i.e. θ = 180°. The gain of the filtenna array with respect to an isotropic radiator has been presented in Fig. 10. From 1–7 GHz, the gain varies from -11.3–7.4 dBi; with the two peak values, i.e. 6.7 dBi and 7.4 dBi, being at the two WLAN frequencies. Efficiency result echoes the gain result and is shown in the same figure. The efficiency result shows two peaks, corresponding to the two WLAN bands of 2.4 GHz and 5.8 GHz. Both peaks are present at more than 70 %. In the rest of the band, the efficiency is less than 15 %.



(a)



(b)

Figure 9 Radiation patterns at (a) 2.4 GHz and (b) 5.8 GHz.

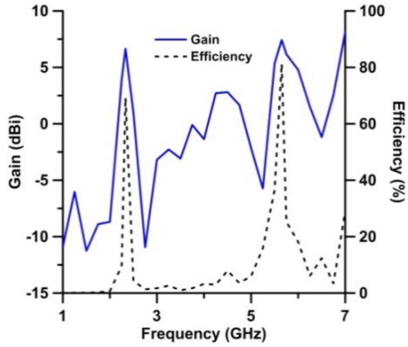


Figure 10 Gain and efficiency.

F) Comparison with Other Works

Table II presents a comparison of various others works, as listed in the references, in which antenna arrays with filters were also developed. Note that the values listed are the maximum of their respective parameters as reported in the works and N/P for a value indicates as "not presented".

Reference	Return Loss (dB)	Gain (dBi)	Array Structure	Filter Order	Number of Bands	Spurious Harmonics Rejected
2	18	11 & 10.6	1x4	2	Dual	No
3	20	9	2x2	3	Single	Yes
4	13	N/P	1x2	4	Single	No
5	23	5.9	1x2	4	Single	Yes
This Work	35 & 30	6.7 & 7.4	1x2	2	Dual	Yes

Table 2 Comparison of various other works.

IV. CONCLUSION

In this paper, a WLAN dual-band (2.4 GHz and 5.8 GHz) 1x2 antenna array, integrated with two pseudo-interdigital bandpass filters, has been designed and presented. Initially, a standalone antenna array was designed and was found to have spurious harmonics in addition to the two main operational WLAN frequencies. The integrated filters are a means of rejecting the spurious harmonics that are present in the antenna array while keeping the two fundamental resonant frequencies intact. The results of the two filters have been presented and show them to be centred at the two main frequencies. The two filters were then integrated within the standalone array. The filtenna array was then simulated, fabricated and measured. Simulation and measurement results of the filtenna array have been shown and are as desired. Although the obtained results show a little reduction in the return loss at the two fundamental

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frequencies, the ensuing measured return loss at the two frequencies is still very good. Furthermore, the suppression of the spurious harmonics in the antenna band has been reasonably achieved. The proposed modelling and design could be implemented for other filtering arrays.

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