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Artificial neural network approach for analyzing mutual coupling in a rectangular MIMO antenna

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Abstract A wideband rectangular patch antenna resonating at 3.5 GHz and 8 GHz frequencies is developed on a flexible substrate, which can be used for wearable applications. The proposed antenna gives a wide impedance bandwidth of 116%, operating from 2.5 GHz to 9.5 GHz, covering most of the ultra-wideband (UWB) operating frequency range. A two-element multiple-input multiple-output (MIMO) system is developed using the proposed antenna, and the mutual coupling between the two antennas for various separations and frequencies is analyzed by using artificial neural networks (ANNs). The neural structure is trained by using different ANN algorithms and a comparative study is made between them. It is shown that, quasi-Newton (QN) and quasi-Newton multi layer perceptron (QN-MLP) algorithms are better in terms of training, testing errors, and correlation coefficient.

Keywords flexible substrate, multiple-input multiple-output (MIMO) systems, artificial neural networks (ANNs), mutual coupling, impedance bandwidth

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1 Introduction

In everyday life, the communication technology plays vital role in different areas such as medical, civil, sport wear, wild life study, and military domains. The emerging developments in wireless communications and recent advancements in antenna technology have shown the researchers a new way of utilizing the antennas in daily life. Recently, the researchers are finding the ways to merge ultra-wideband (UWB) technology, wearable systems technology, and textile technology. All these together have resulted in demand for flexible substrate antennas, which can be easily attached to a human body or piece of clothing.

In the present wireless communications, paper material is one of the promising options for the flexible substrate antennas, due to many of its inherent advantages [1]. Paper is an organic-based substrate with its wide availability, and the mass production of paper makes it the cheapest material ever made. Due to the low surface profile of paper, it is suitable for fast printing processes, such as inkjet printing, instead of the traditional metal etching techniques [2]. This also enables all the components, such as antennas, memory, IC, batteries, and sensors, to be easily embedded on paper modules [3].

The multiple-input multiple-output (MIMO) technology is the current advanced technology for achieving larger data rates and high bandwidth efficiencies in modern wireless communications. The MIMO technology was first proposed by the pioneer Foschini [4], where employing multiple antennas at the transmitter and receiver side of a communication system will improve the data rates.

In MIMO systems, mutual coupling between the antennas is one of the important parameters that affect the performance of the communication system. This mutual coupling arises due to the close spacing of antennas in the MIMO system. The mutual coupling even affects the channel capacity of the MIMO system as discussed in

Ref. [5], and the main sources of this mutual coupling are studied in Refs. [6] and [7].

Using of artificial neural networks (ANNs) for solving the non-linear problems of microwave devices and circuits is the latest paradigm [8]. The neural networks are trained to process any non-linear input-output relationship from corresponding data, which result their usage in number of areas, such as radio frequency (RF) and microwave computer-aided design (CAD) problems, pattern recognition, speech processing, control, biomedical engineering, etc.. The data for a neural network model can be developed from measured or simulated or calculated microwave data through the process called *training*. Once the ANN model is properly trained, it can be used for analyzing the given test data quickly and accurately. The normal electromagnetic (EM) simulation tool can handle the task only for the specified parameters in the specified range only. However, the ANN can handle any number of parameters for any range of values, once it is properly trained [9]. This is the main reason for selecting the ANN tool to analyze the mutual coupling for various separations and frequencies for the proposed antenna.

In the present paper, a wideband rectangular patch antenna resonating at a dual band of 3.5 GHz and 8 GHz frequencies is developed on a paper substrate. The

proposed antenna operates in the frequency range 2.5 GHz – 9.5 GHz giving an impedance bandwidth of 116%. A two-element MIMO system is formed using the proposed antenna, and the mutual coupling between the two antennas is studied for various separations using ANNs. The ANNs are trained with different training algorithms. It is shown that, quasi-Newton (QN) and quasi-Newton multi layer perceptron (QN-MLP) algorithms are better in terms of testing error and correlation coefficient.

2 Antenna design

A rectangular patch antenna of each side of 30 mm is formed on a paper substrate with $\epsilon_r = 3$, as shown in Fig. 1. The permittivity value of paper material ranges from 1.5 to 4 [10], and in the present work a coated paper with intermediate permittivity value of 3 is chosen as the substrate. The dimensions of the antenna are given as $W = 50$ mm, $L = 45$ mm, $W_p = 30$ mm, $L_p = 30$ mm, $P = 5$ mm, height of the substrate $h = 1$ mm and is fed with a coaxial feed.

A normal rectangular patch antenna gives the bandwidth only in the range of 3%–5% [11]. To improve the bandwidth of the antenna, the ground plane is reduced.

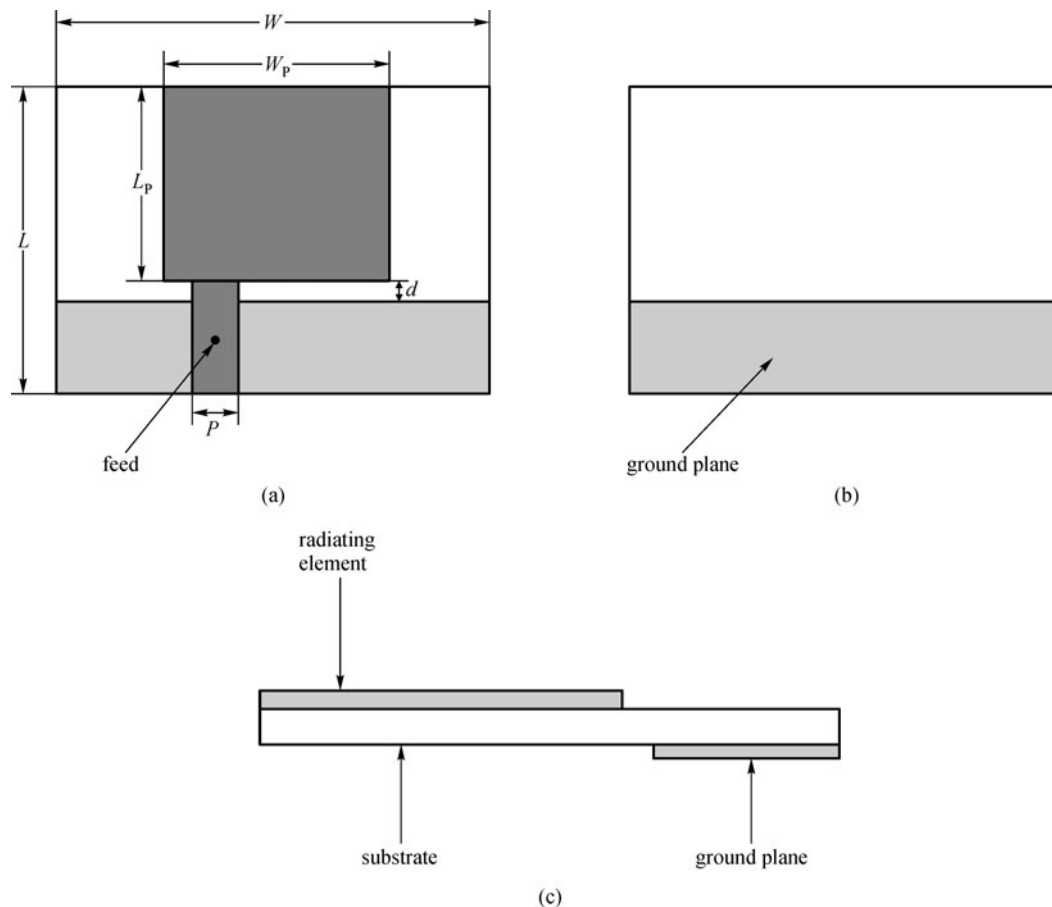


Fig. 1 Proposed rectangular patch antenna. (a) Top view; (b) bottom view; (c) side view

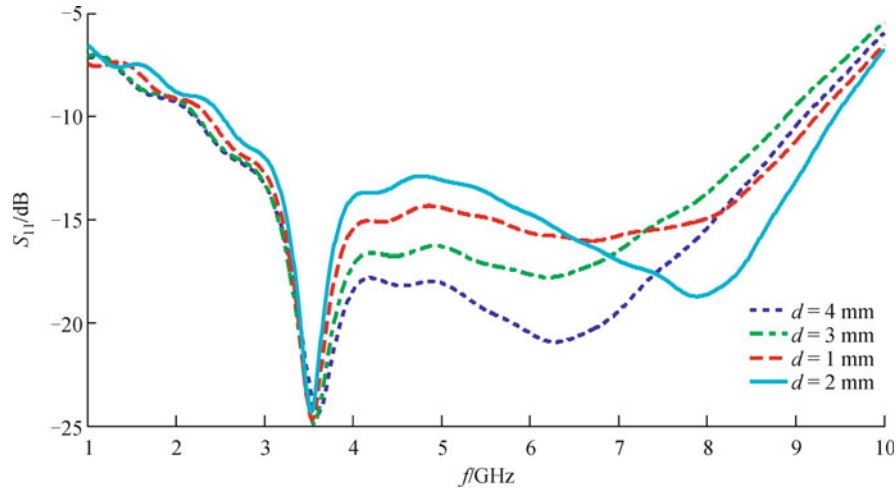


Fig. 2 Return loss for different values of d

This is due to the fact that, when the ground plane is reduced, multiple resonant frequencies are generated and these frequencies couple each other resulting in improved impedance bandwidth [12]. A gap analysis is made for different values of the distance d and the return loss, as shown in Fig. 2. From the figure, it can be observed that better return loss at both the resonant frequencies is obtained for $d = 2$ mm.

The proposed antenna is shown to give a wide bandwidth of 116%, resonating at 3.5 GHz and 8 GHz and operating in the frequency range from 2.5 GHz to 9.5 GHz, as shown in Fig. 2. This operating frequency range covers most of the UWB frequency range (which is 3.1 GHz to 10.6 GHz) and as the substrate material used is paper, it is well suited for the UWB RFID applications [13]. Besides, paper substrate antennas are environment friendly and play major role in future trend *Green Electronics* and also in wearable applications [14].

In the following section, a two-element MIMO system is developed and the mutual coupling between the two antennas is analyzed for various separations using the ANNs. A comparative analysis is made among different ANN algorithm approaches.

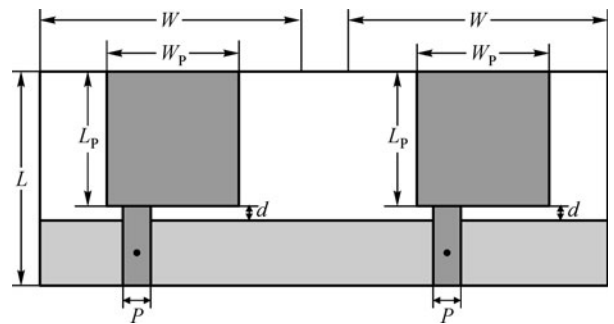


Fig. 3 Two-element MIMO array using the proposed antenna

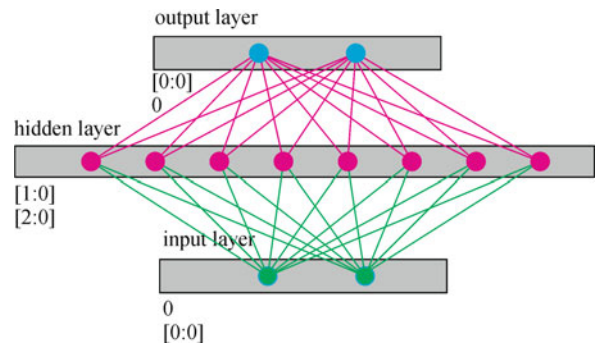


Fig. 4 Neural network structure

3 Mutual coupling analysis in MIMO array using ANN

As mentioned earlier, MIMO systems are the most promising option in the present wireless communications, where higher data rates and spectral efficiencies are desired. Here, a two-element MIMO system is formed using the proposed antenna, as shown in Fig. 3. The neural structure shown in Fig. 4 is used for analyzing the mutual coupling between the antennas in the MIMO system. The operating frequency f and the distance x between the two antennas are given as the inputs to the neural network

structure. The mutual coupling S_{21} is taken as the output.

The main reason for using ANN to analyze the mutual coupling in the MIMO array is to predict its value for various distances and various operating frequencies, which is not possible with an EM simulation tool. ANN models accuracy depends on the amount of data presented to it during training. A well-distributed, accurately simulated or measured and sufficient data are the basic requirement to obtain an efficient model.

The data sets are generated from the simulation software FEKO and contain nearly 6000 samples. For training, 4000 samples are used and for testing 2000 samples are utilized. The neural networks are trained with a learning rate of 0.25 for 1000 epochs. The main objective of the training process is to minimize the error between the actual output and target output of the ANN. Selection of training parameters and the entire training process mostly depend on experience besides the type of problem at hand. After several trials during the training, it is observed that the below mentioned three-layered network yields better results.

The neural model for the modeling of mutual coupling is trained with different learning algorithms, namely, sparse training (ST), conjugate gradient (CG), adaptive back propagation (ABP), quasi-Newton multi layer perceptron (QN-MLP), quasi-Newton (QN), Huber-quasi-Newton (HQN), and simplex method (SM).

The training and testing errors generated in modeling the mutual coupling of the developed MIMO array are shown in Table 1. From the results, it can be observed that QN and QN-MLP algorithms give good results compared to the other algorithms. Both the algorithms give least training and testing errors and maximum correlation coefficients. This implies that the QN and QN-MLP algorithms are suitable for calculating mutual coupling in microstrip MIMO antennas with maximum correlation. The correlation coefficient describes the amount of correlation

Table 1 Comparison of training and testing errors with various algorithms

(a) Training			
learning algorithms	training error		
ST	0.0465572		
CG	0.0454214		
ABP	0.0454341		
QN-MLP	0.03662274		
QN	0.0366226		
HQN	0.0356824		
SM	0.0366248		

(b) Testing			
learning algorithms	average error	worst case error	correlation coefficient
ST	4.8357515	53.51073	0.99778634
CG	4.8626294	52.03791	0.99778163
ABP	4.8626294	52.03791	0.99778163
QN-MLP	3.8217053	44.985805	0.99854547
QN	3.8217053	44.985805	0.99854547
HQN	3.706239	48.653835	0.9985055
SM	3.8213212	45.682884	0.9985424

between the trained and tested data.

Due to the better performance of QN algorithms, these are used for modeling the mutual coupling between the two antennas by varying the distance between them. The range of the distance x between the two antennas is selected in the range from 0 to 30 mm and the variation of mutual coupling with respect to distance is obtained using the neural network structure as shown in Fig. 5(a). From the results, it can be seen that the mutual coupling is increased as the distance between the antennas is decreased. This is obvious, as the distance between the antennas is decreased, the interaction of the EM fields between the antennas increases, thus increasing the mutual coupling. The value of mutual coupling for different frequencies is shown in Fig. 5(b).

As discussed earlier, the beauty of ANN is to model the mutual coupling for a range of separations and frequencies accurately in a short span of time. From Fig. 5, we can readily estimate the amount of mutual coupling for the proposed MIMO array. The comparison between the simulated and ANN calculated mutual coupling is shown in Fig. 6. From Fig. 6, it is obvious that the ANN calculated mutual coupling almost follows the simulated mutual coupling, except at the peaks giving a maximum variation of ± 3 dB.

As mentioned earlier, the main idea behind using the ANN for evaluating the mutual coupling is to minimize the high computational time of EM simulators. A normal EM simulator gives the mutual coupling only for a single specified separation between the antennas and finding the coupling for various distances between the antennas is computationally extensive. However, once ANN is properly trained, the coupling can be calculated for a set of separations and the practical antenna array can be fabricated at the convenient coupling levels, helping the MIMO antenna designer.

4 Conclusion

A rectangular patch antenna resonating at the dual band of frequencies 3.5 GHz and 8 GHz is developed on a paper substrate, which is cheaper and easier to use for UWB RFID applications. The proposed antenna gives a -10 dB impedance bandwidth of 116%, covering the frequency band from 2.5 GHz to 9.5 GHz. A two-element MIMO system is developed using the proposed antenna, and the mutual coupling between the antennas is studied by using ANNs for a specified range of separation between the antennas and for various frequencies. The ANN structure is trained with various training algorithms and the better results in terms of training, testing, and correlation coefficient are obtained with QN and QN-MLP algorithms. Hence, these algorithms are used for modeling the mutual coupling between the antennas.

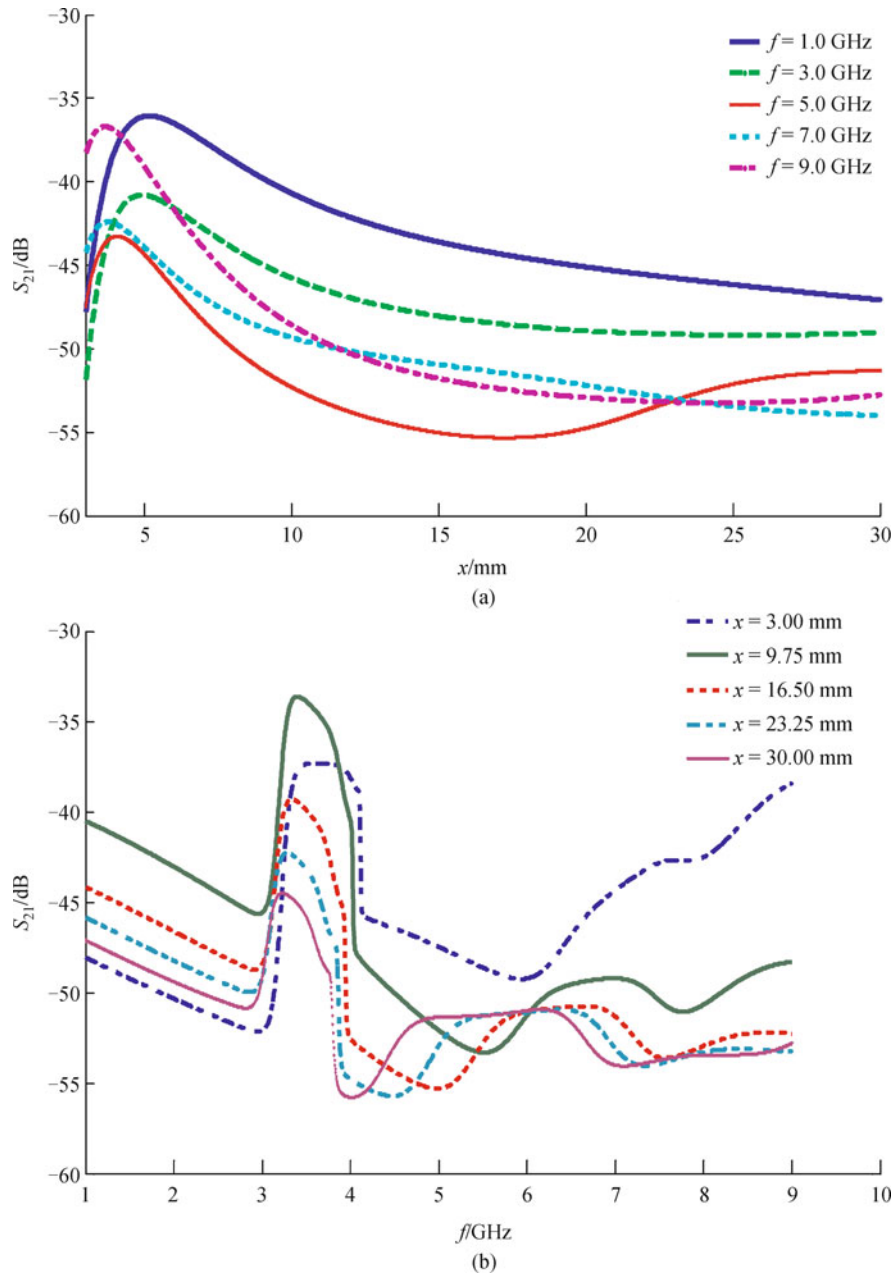


Fig. 5 Mutual coupling generated by neural network (a) with varying distance and (b) with varying frequency

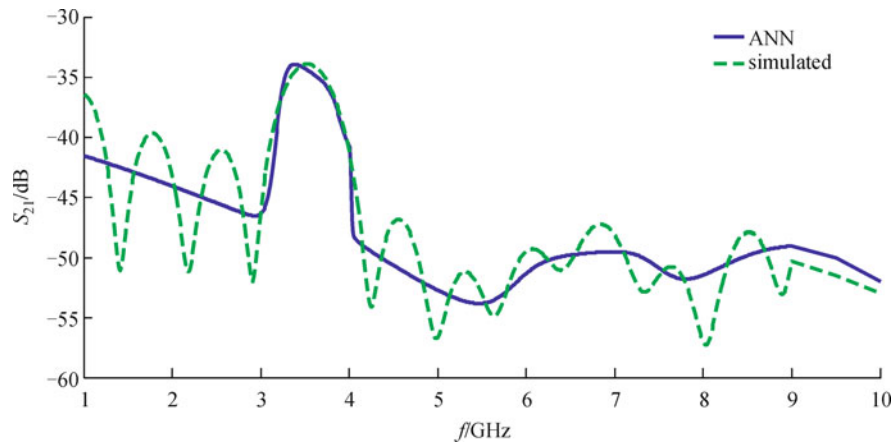


Fig. 6 Comparison between simulated and ANN calculated mutual coupling for $x = 10$ mm

References

1. Yang L, Rida A, Vyas R, Tentzeris M M. RFID tag and RF structures on a paper substrate using inkjet-printing technology. *IEEE Transactions on Microwave Theory and Techniques*, 2007, 55(12): 2894–2901
2. Tentzeris M M, Yang L, Rida A, Traille A, Vyas R, Wu T. RFID's on paper using inkjet-printing technology: Is it the first step for UHF ubiquitous “cognitive intelligence” and “global tracking”? In: *Proceedings of the 1st Annual RFID Eurasia*. 2007, 1–4
3. Rida A, Vyas R, Basat S, Ferrer-Vidal A, Yang L, Bhattacharya S K, Tentzeris M M. Paper-based ultra-low-cost integrated RFID tags for sensing and tracking applications. In: *Proceedings of the 57th Electronic Components and Technology Conference*. 2007, 1977–1980
4. Foschini G J, Gans M J. On limits of wireless communications in a fading environment when using multiple antennas. *Wireless Personal Communications*, 1998, 6(3): 311–335
5. Abouda A A, Häggman S G. Effect of mutual coupling on capacity of MIMO wireless channels in high SNR scenario. *Progress in Electromagnetics Research*, 2006, 65: 27–40
6. Humphrey D E J, Fusco V F. A mutual coupling model for microstrip patch antenna pairs with arbitrary orientation. *Microwave and Optical Technology Letters*, 1998, 18(3): 230–233
7. Nikolic M M, Djordevic A R, Nehorai A. Microstrip antennas with suppressed radiation in horizontal directions and reduced coupling. *IEEE Transactions on Antennas and Propagation*, 2005, 53(11): 3469–3476
8. Zhang Q J, Gupta K C, Devabhaktuni V K. Artificial neural networks for RF and microwave design — from theory to practice. *IEEE Transactions on Microwave Theory and Techniques*, 2003, 51(4): 1339–1350
9. Kabir H, Wang Y, Yu M, Zhang Q J. Neural network inverse modeling and applications to microwave filter design. *IEEE Transactions on Microwave Theory and Techniques*, 2008, 56(4): 867–879
10. Rida A H. Conductive inkjet printed antennas on flexible low-cost paper-based substrates for RFID and WSN applications. Thesis for the Master's Degree. Atlanta, GA: Georgia Institute of Technology, 2009
11. Bhardwaj D, Bhatnagar D, Sancheti S, Soni B. Radiations from double notched square patch antenna on FR4 substrate. *Journal of Microwaves, Optoelectronics and Electromagnetic Applications*, 2008, 7(2): 54–64
12. Azim R, Tariqul Islam M, Misran N, Cheung S W, Yamada Y. Planar UWB antenna with multi slotted ground plane. *Microwave and Optical Technology Letters*, 2011, 53(5): 966–968
13. Yang T, Tian X J. A novel heart-shaped monopole antenna for UWB and RFID applications. *Microwave and Optical Technology Letters*, 2011, 53(10): 2288–2291
14. Osman M A R, Rahim M K A, Azfar M, Samsuri N A, Zubir F, Kamardin K. Design, implementation and performance of ultra-wideband textile antenna. *Progress in Electromagnetics Research B*, 2011, 27: 307–325