Metamaterial-based Printed Circuit Antenna for Biomedical Applications

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Abstract

Due to the rapid increase for novel antenna designs to satisfy the modern wireless technologies, different techniques are proposed to improve their performance. For this purpose, this paper presents a novel technique to design a miniaturized microstrip antenna structure based on metamaterial (MTM) transmission line defected patch. The proposed antenna is introduced as part of wearable systems with minimum back radiation toward the human body. Therefore, the antenna is constructed of a closed loop linked to an interdigital capacitor to magnify the electric field fringing at the patch core. The proposed antenna when printed on a FR-4 substrate at 0.6GHz in the first mode shows S_{11} impedance matching less than -10dB. The proposed antenna performance is evaluated numerically based on CST MWS in terms of radiation pattern. A neural network is invoked to optimize the proposed antenna performance at the required frequency band. Finally, the proposed antenna performance is validated using another software package based on HFSS simulator to provide good agreement with percentage of error less than 4.4%.

Keywords: CST MWS, Neural network, Biomedical, MTM, HFSS.

Biyomedikal Uygulamalar için Metamalzeme Bazlı Baskılı Devre Anteni

Öz

Modern kablosuz teknolojileri gereksinimleri için yeni anten tasarımlarının hızla artması nedeniyle, performans iyileştirme adına farklı teknikler önerilmektedir. Bu amaçla, bu makale, metamalzeme (MTM) tabanlı minyatür bir mikroşerit anten yapısı tasarlamak için yeni bir teknik sunmaktadır. Önerilen anten, insan vücuduna doğru minimum geri radyasyonla giyilebilir sistemlerin bir parçası olarak önerilmektedir. Bu nedenle anten, yama çekirdeğindeki elektrik alanı saçaklarını büyütmek için bir interdijital kapasitör ile bağlantılı kapalı bir döngüden yapılmıştır. Önerilen anten, birinci modda 0.6GHz'de bir FR-4 substratı üzerine basıldığında,-10dB'den daha az S_{11} empedans eşleşmesini gösterir. Önerilen anten performansı, radyasyon modeli açısından CST MWS'ye dayalı olarak sayısal olarak değerlendirilmiştir. Önerilen anten performansını gerekli frekans bandında optimize etmek için bir sinir ağı oluşturulmuştur. Son olarak, önerilen anten performansı, %4,4'ten daha az hata yüzdesi ile iyi bir uyum sağlamış ve bu değerler HFSS simülatörüne dayalı başka bir yazılım paketi kullanılarak doğrulanmıştır.

Anahtar Kelimeler: CST MWS, Sinir ağı, Biyomedikal, MTM, HFSS.

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1. Introduction

Metamaterials (MTM) were first proposed by Viktor Veselago in 1967 [1]. Artificial materials with nontraditional properties [2] may be used to characterize such structures. Negative permittivity and negative permeability are properties of these materials that enable electromagnetic waves to propagate backwards [3]. Pendry [4] proposed an interesting subwavelength feature that was realized as a split ring resonator (SRR) in 1999 to achieve negative permeability. SRR is essentially an LC circuit tank with equal inductance (L) and capacitance (C) between two concentric rings resonating at a particular frequency [4]. The changes in scattering parameters (S-parameters) with respect to the introduction of a sample under test (SUT) can be transferred via a certain algorithm to retrieve the materials characterizations in this step. Microwave sensing is a proven tool for liquid characterization that has been used for over a decade [5]. Researchers have been involved in SRRs [6], complementary SRRs (CSRRs) [3], open CSRRs (OCSRRs) [4], closed ring resonator [5], and other miniaturized microwave resonators [6] based on transmission lines for biomedical applications [6]. The electromagnetic properties of these structures are affected by the frequency at which they operate and how the consistency factor varies with different liquid introductions [7]. Liquid characterizations can be discussed by calculating S-parameter coefficients and complex dielectric parameters of SUT [8]. This has offered the biological, pharmaceutical, and fuel industries a new sensing network [9]. The vast majority of microwave biological sensors are installed in ultra-thin cylindrical pipes [10] or slotted cylindrical tubes [11]. Materials under test losses can be extracted for quality detection by measuring S-parameter magnitudes at a specific frequency [12]. However, due to the problem of skin depth penetration, such technology has been found to be a major concern in the resolution of high-losses [13].

In this paper, a novel antenna design is suggested for biomedical applications based on a single port antenna element and MTM transmission line structure is proposed. The MTM is made up of a closed loop ring and an interdigital capacitor framework. The proposed structure is described in Section 2 with all geometrical descriptions. The parametric research and the analysis process are also discussed in Section 2. In Section 3, the antenna results are discussed. Finally the paper is concluded in Section 4.

2. Material and Method

2.1. Antenna Design Details

The proposed antenna is mounted on a FR-4 substrate with a thickness of h=1.6 mm and a dielectric constant of ε_r=4.3 and a loss tangent of tanδ=0.025. The copper metal is 35 µm. The planned antenna has a 30×30 mm^2 footprint. The antenna is fed by a 50 Ω microstrip transmission line with a width of 7.25mm and a length of 1.5mm that is extended to touch the patch and attached directly to the radiating structure. Figure 1 depicts the proposed antenna architecture in details. Table 1 contains all of the geometrical aspects of Figure 1.
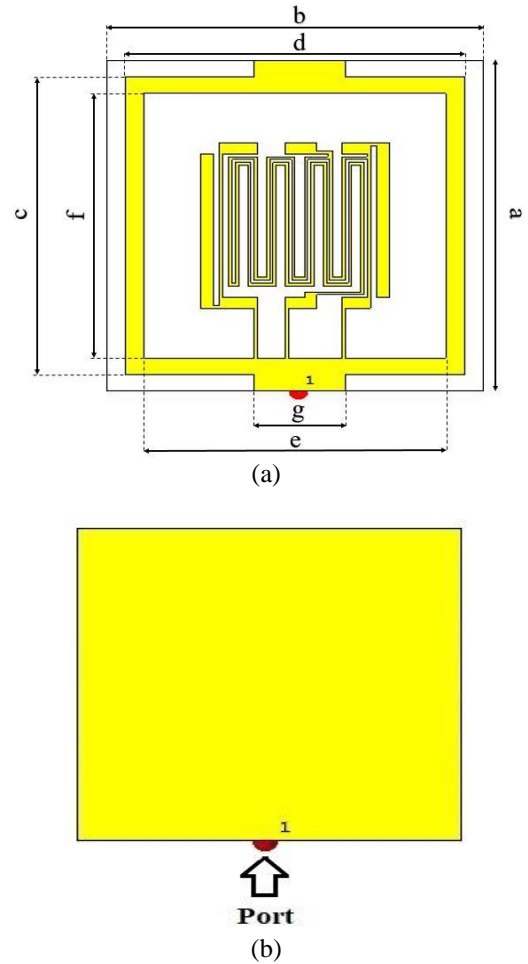

(a)

(b)

Figure 1. Antenna design: (a) Front view and (b) Back view.

Table 1. Geometrical details of the proposed antenna.

Parameter	Value (mm)
A	30
B	30
C	27
D	27
E	24
F	24
G	7.25

2.2. Antenna Optimization Study

The proposed antenna dimensions are parametrically studied after invoking a neural network architecture. In this network, a knowledge-based hybrid neural network (KBHNN) model is for designing of microstrip antennas which is used for ISM band applications. In Figure 2, a synthesis model is defined as to obtain dimensions (W, L) of the antenna while providing the resonant frequency (f_r), height of the dielectric substrate (h), quality factor (Q), bandwidth (B.W), and return loss spectra (S_{11}) at the input of the ANN model.
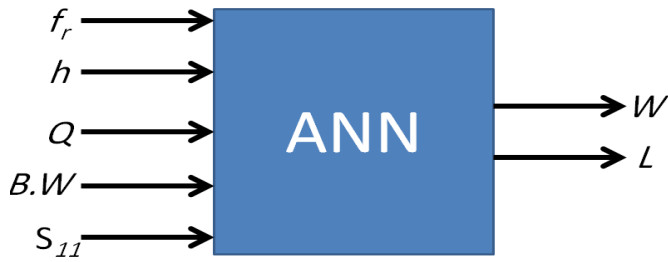
Figure 2. The synthesis of microstrip patch using ANN model.

It's worth noting that neural network models are extremely versatile methods for designing highly nonlinear devices. In our case, we used a neural network model to calculate the proposed patch's key dimensions, including the distance between internal dimension data. Bandwidth (B.W), resonant frequency (f_r), gain (G), quality factor (Q), and S11 magnitude have all been used as input to the model. As shown in Figure 3, the network architecture consists of one hidden layer and tow neurons in the output layer.
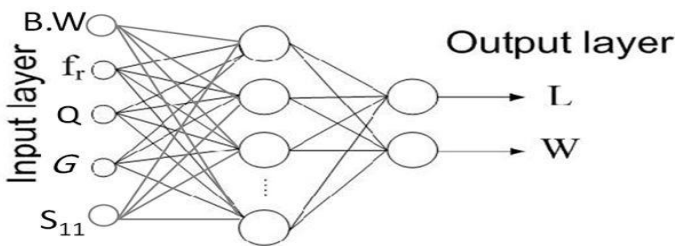

Figure 3. Architecture of neural network model.

As training data for the proposed ANN, about 50 samples are collected by varying the dimensions of the proposed microstrip patch antenna using the CST MWS software package [14], as shown in Table 2. As will be shown later, this information is used to synthesis a patch antenna.

Table 2. Input antenna performance.

L/mm	W/mm	f_r/ GHz	$|S_{11}|$/ dB	G/ dB	Q/ %	B.W/ MHz
70	63	0.1091	24.5	0.1091	12	10
69	62	0.112	22.1	0.112	11	10
68	61	0.115	22.4	0.115	11	11
67	60	0.106	23.1	0.106	12	12
66	59	0.115	24.7	0.115	15	11
65	58	0.111	23.9	0.111	22	9
64	57	0.123	26.9	0.123	9	10
63	56	0.193	28.1	0.193	8	11
62	55	0.191	28.4	0.191	21	12
61	54	0.103	22.8	0.103	31	11
60	53	0.109	22.3	0.109	9	11
59	52	0.108	25.3	0.108	12	7
58	51	0.121	27.2	0.121	11	9
57	50	0.111	22.9	0.111	13	8
56	49	0.156	26.3	0.156	17	9
55	48	0.116	23.1	0.116	15	5
54	47	0.182	22.9	0.182	10	6
53	46	0.174	23.0	0.174	9	4
52	45	0.091	23.1	0.091	16	10
51	44	0.098	23.1	0.098	13	11
50	43	0.092	23.9	0.092	10	13
49	42	0.109	24.1	0.109	11	9
48	41	0.106	23.9	0.106	12	10
47	40	0.110	22.4	0.110	11	11
46	39	0.122	22.4	0.122	7	4
45	38	0.133	27.3	0.133	7	7
44	37	0.124	27.9	0.124	9	5
43	36	0.111	24.1	0.111	11	10
42	35	0.110	27.8	0.110	13	4
41	34	0.113	27.4	0.113	12	7
40	33	0.091	26.3	0.091	10	10
39	32	0.094	25.6	0.094	7	6
38	31	0.092	26.1	0.092	11	8
37	30	0.109	25.3	0.109	9	4
36	29	0.101	25.9	0.101	7	6
35	28	0.105	25.2	0.105	12	2
34	27	0.189	24.2	0.189	11	12
33	26	0.188	23.4	0.188	10	11
32	25	0.177	24.4	0.177	9	7
31	24	0.109	27.8	0.109	12	6
30	23	0.110	27.3	0.110	11	2
29	22	0.112	27.0	0.112	9	4
28	21	0.195	24.9	0.195	4	8
27	20	0.196	25.2	0.196	5	9
26	19	0.179	25.1	0.179	8	5

The ANN training loss results for the proposed microstrip patch antenna synthesis is shown in Figure 4. It shows that 100 epochs are required for ANN training loss to get reduced from 100 to nearly 10^{-2}.
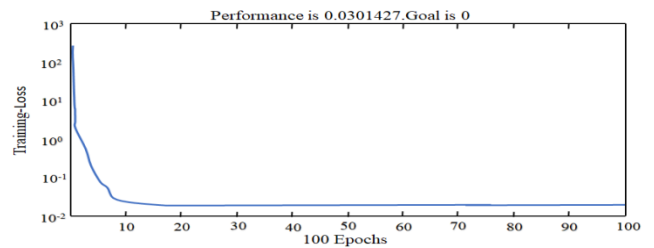

Figure 4. ANN training results for synthesis of microstrip patch antenna.

3. Results and Discussion

The proposed neural network model is applied for given f_r = 0.63 GHz with $|S_{11}|$=16dB and a bandwidth of 0.6GHz to 0.65GHz with G = 1.5dBi. The antenna dimensions obtained through the network simulation model are summarized in Table 3. It is seen that when the percentage errors are calculated and compared to the simulated ones, it seems there is a very good fit corresponding to 0.044 percent error. Therefore, according to the obtained dimensions, the proposed antenna performance is validated in another software package of HFSS simulator [15]. The simulated results from both software packages show excellent agreement as seen in Figure 5 for the S_{11} and gain spectra.

Table 3. Obtained antenna dimensions from CST MWS and HFSS with respect to ANN model.

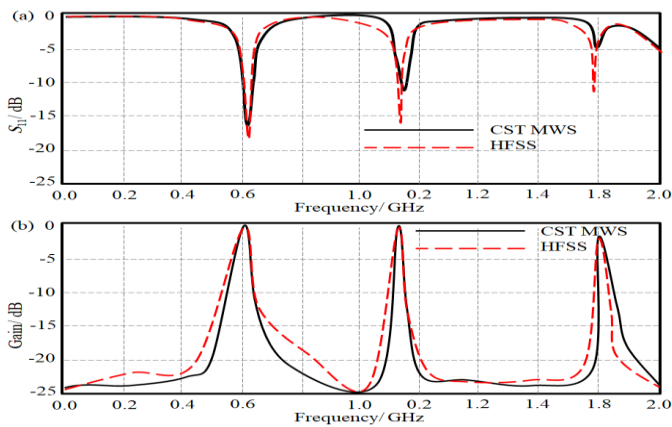| Dimension/ mm	CST	HFSS	ANN	Error
L	30	30.5	31.3	0.044
W	24	23.4	22.9	0.041

Figure 5. Validated results: (a) S11 and (b) gain spectra.

3. Conclusions and Recommendations

A design of a microstrip antenna is proposed based on MTM. The proposed antenna is designed to show a frequency resonance at 0.63 GHz with $|S_{11}|$=16dB and a bandwidth of 0.6GHz to 0.65GHz with G = 1.5dBi. Therefore, a neural network is proposed and parametric study is invoked based on CST MWS. The obtained results from CST MWS are used as training data to optimize the antenna dimensions at the desired performance. The antenna dimensions are calculated based on the proposed neural network. The obtained design performances are validated numerically using HFSS simulator. It is believed that the neural network models could be the alternative candidate for antenna design to avoid complex and long lasting computations.

References

[1] Mahmood, S.N., Ishak, A.J., Saeidi, T., Soh, A.C., Jalal, A., Imran, M.A., Abbasi, Q.H. (2021) Full ground ultra-wideband wearable textile antenna for breast cancer and wireless body area network applications. *Micromachines*, 12, 322. https://doi.org/10.3390/ mi12030322.

[2] Ali, J.K., Ahmed, E.S. (2012) A new fractal based printed slot antenna for dual band wireless communication applications. *in Proc. Progress in Electromagnetics Research Symp.*, Kuala Lumpur, Malaysia.

[3] Ali, J., Abdulkareem, S., Hammoodi, A., Salim, A., Yassen, M., Hussan, M., & Al-Rizzo, H. (2016) Cantor fractal-based printed slot antenna for dual-band wireless applications. *International Journal of Microwave and Wireless Technologies*, 8(2), 263-270.

[4] Elwi, T. A. (2019) Printed microwave metamaterial-antenna circuitries on nickel oxide polymerized palm fiber substrates. *Sci. Rep.*, Vol. 9, No. 2174, 1–14.

[5] Elwi, T. A. (2019) Novel UWB printed metamaterial microstrip antenna based organic substrates for RF-energy harvesting applications. *International Journal of Electronics and Communications*, Vol. 101, No. 9, 1–10.

[6] Elwi, T. A. and B. A. Ahmed (2018) A fractal metamaterial based printed dipoles on a nickel oxide polymer palm fiber substrate for Wi-Fi applications. *International Journal of Electronics and Communications*, Vol. 96, No. 23, 122–129.

[7] Hatem, G. M., A. J. Salim, T. A. Elwi, et al. (2019) Wunderlich curve fractal dipole antenna for dualband wearable RFID applications. *Journal of Engineering and Applied Sciences*, Vol. 14, No. 4, 1093–1099.

[8] Elwi, T. A., A. I. Imran, and Y. Alnaiemy (2015) A miniaturized lotus shaped microstrip antenna loaded with EBG structures for high gain-bandwidth product applications. *Progress in Electromagnetics Research C*, Vol. 60, 157–167.

[9] Elwi, T. A. (2018) A slotted lotus-shaped microstrip antenna based EBG structures. *Wireless Communication Technology*, Vol. 2, No. 1, 1–24.

[10] Imran, A. I. and T. A. Elwi (2017) A cylindrical wideband slotted patch antenna loaded with frequency selective surface for MRI applications. *Eng. Sci. & Tech., an Int. Jou.*, Vol. 20, No. 3, 990–996.

[11] Elwi, T. A., Z. A. Al-Hussain, and Tawfeeq O.A. (2019) Hilbert metamaterial printed antenna based on organic substrates for energy harvesting. *IET Micr., Ant. & Prop.*, Vol. 10, No. 2, 1–8.

[12] Elwi, T. A., D. A. Jassim, and H. H. Mohammed (2020) Novel miniaturized folded UWB microstrip antenna-based metamaterial for RF energy harvesting. *Int. J. Commun. Syst.*, Vol. 1, No. e4305, 1–15.

[13] Elwi, T. A. (2017) Electromagnetic band gap structures based an ultra-wideband microstrip antenna. *Microwave and Optical Letters,* 59(4), 827–834.

[14] CST Microwave Studio (CST MWS). (2020) http://www.cst.com.

[15] High Frequency Structure Simulator (HFSS). (2020) http://www.ansoft.com.