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Datum: 08.06.2022.

UNIVERZITET CRNE GORE

- Centru za doktorske studije -

- Senatu -

O V D J E

U prilogu dostavljamo Odluku Vijeća Elektrotehničkog fakulteta sa sjednice od 26.05.2022. godine i obrazac **D2**, sa pratećom dokumentacijom, za kandidata MSc **Luku Lazovića**, na dalji postupak.

D E K A N,
Prof. dr Saša Mujović

ISPUNJENOST USLOVA DOKTORANDA

OPŠTI PODACI O DOKTORANDU			
Titula, ime, ime roditelja, prezime	MSc Luka Ljubo Lazović		
Fakultet	Elektrotehnički fakultet		
Studijski program	Doktorske studije elektrotenike		
Broj indeksa	1/15		
NAZIV DOKTORSKE DISERTACIJE			
Na službenom jeziku	Analiza i dizajn antena zasnovanih na fraktalnoj geometriji		
Na engleskom jeziku	Antennas Based on Fractal Geometry: Analysis and Design		
Naučna oblast	Elektrotehnika/Elektromagnetika/Antene		
MENTOR/MENTORI			
Prvi mentor	Prof. dr Ana Jovanović	Elektrotehnički fakultet, Univerzitet Crne Gore, Podgorica, Crna Gora	Elektrotehnika/ Elektromagnetika/ Antene
KOMISIJA ZA PREGLED I OCJENU DOKTORSKE DISERTACIJE			
Dr Branka Jokanović, naučni savjetnik		Institut za fiziku, Univerzitet u Beogradu, Beograd, Srbija	Elektrotehnika/ Telekomunikacije/ Mikrotalasna tehnika
Prof. dr Ana Jovanović, redovni profesor		Elektrotehnički fakultet, Univerzitet Crne Gore, Podgorica, Crna Gora	Elektrotehnika/ Elektromagnetika/ Antene
Prof. dr Vesna Rubežić, redovni profesor		Elektrotehnički fakultet, Univerzitet Crne Gore, Podgorica, Crna Gora	Elektrotehnika/ Mikrotalasna tehnika
Datum značajni za ocjenu doktorske disertacije			
Sjednica Senata na kojoj je data saglasnost na ocjenu teme i kandidata	16.10.2017. godine		
Dostavljanja doktorske disertacije organizacionoj jedinici i saglasanost mentora	12.05.2022. godine		
Sjednica Vijeća organizacione jedinice na kojoj je dat prijedlog za imenovanje komisija za pregled i ocjenu doktorske disertacije	26.05.2022. godine		
ISPUNJENOST USLOVA DOKTORANDA			

U skladu sa članom 38 pravila doktorskih studija kandidat **je** dio sopstvenih istraživanja vezanih za doktorsku disertaciju publikovao u časopisu sa **(SCI/SCIE)** liste kao prvi autor.

Spisak radova doktoranda iz oblasti doktorskih studija koje je publikovao u časopisima sa (upisati odgovarajuću listu)

1. **Lazović, L.**; Jokanovic, B.; Rubežić, V.; Radovanovic, M.; Jovanović, A. Fractal Cardioid Slot Antenna for Super Wideband Applications. Electronics 2022, 11, 1043. https://doi.org/10.3390/electronics11071043

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Međunarodne konferencije:

2. **L. Lazovic**, B. Jokanovic, V. Rubezic and A. Jovanovic, (2020): "Uniplanar Ultra-Wideband Cardioid Slot Antenna for Energy Harvesting Application", 2019 27th Telecommunications Forum (TELFOR), pp. 1-4, 2019.

3. **Luka Lazović**, Branka Jokanovic, Vesna Rubežić and Ana Jovanović (2019): "Printed Ultra-Wideband Cardioid Monopole Antenna for Energy Harvesting Application", TELSIKS 2019, Sebia, Niš, October 23-25, 2019.

Obrazloženje mentora o korišćenju doktorske disertacije u publikovanim radovima

Rezultati istraživanja doktoranda MSc Luke Lazovića koji su korišćeni pri izradi doktorske teze su prezentovani kroz jedan rad publikovan u časopisu sa **(SCI/SCIE)** liste, gdje je kandidat prvi autor. Takođe, dio rezultata je prezentovan i na dvije međunarodne konferencije.

U radu " Fractal Cardioid Slot Antenna for Super Wideband Applications" objavljenom u časopisu " *Electronics* " (impakt faktor 2.408), izdavača MDPI na kojem je kandidat prvi autor, predložena je uniplanarna ultra-širokopojasna antena monopol antena zasnovana na fraktalnoj geometriji. Ova antena uz jos dva predložena dizajna zauzima centralno mjesto u doktorskoj disertaciji. Kao osnovni element fraktala upotrijebljena je geometrija kardioide. Antena radi u opsegu od 1.8 GHz do 30 GHz i ima izuzetno male električne dimenzije od svega 0.21 λ x 0.285 λ na najnižoj učestanosti od 1.8 GHz. Antena je projektovana na jeftinom FR-4 supstratu jer je primarno namijenjena za korišćenje u šuirokopojasnom Energy Harvesting-u i u IoT sistemima, ali i u svim ostalim komunikacijama u ovom opsegu. Simulacije su pokazale da antena ima koeficijent refleksije S_{11} ispod -10 dB u cijelom opsegu od 1.8 GHz do 30 GHz, što pokriva sve postojeće komercijalne opsege za 3G, 4G, 5G, Wi-Fi, ISM, satelitske komunikacije i radare. Antena postiže pojačanje do 5 dBi. Eksperimentalnom verifikacijom su potvrđeni rezultati dobijeni simulacijama, tj. potvrđene su dobre performance antene iako je izrađena na jeftinom FR-4 supstratu vrlo jeftinom i nepreciznom tehnologijom. Antena predložena u ovom radu je opisana u glavi 6 doktorata.

Jedan dio rezultata kandidata je prezentovan na međunarodnim konferencijama TELSIKS i TELFOR.
Datum i ovjera (pečat i potpis odgovorne osobe)
U Podgorici, 06.06.2022. godine MP DEKAN UNIVERZITET CRNE GORE Elektrotehnički fakultet

Prilog dokumenta sadrži:

1. Potvrdu o predaji doktorske disertacije organizacionoj jedinici
2. Odluku o imenovanju komisije za pregled i ocjenu doktorske disertacije
3. Kopiju rada publikovanog u časopisu sa odgovarajuće liste
4. Biografiju i bibliografiju kandidata
5. Biografiju i bibliografiju članova komisije za pregled i ocjenu doktorske disertacije sa potvrdom o izboru u odgovarajuće akademsko zvanje i potvrdom da barem jedan član komisije nije u radnom odnosu na Univerzitetu Crne Gore

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Broj: 02/1-542/2
Datum: 12.05. 2022

Na osnovu službene evidencije i dokumentacije Elektrotehničkog fakulteta u Podgorici, izdaje se

POTVRDA

MSc **Luka Lazović**, student doktorskih studija na Elektrotehničkom fakultetu u Podgorici, dana 12.05.2022. godine dostavio je ovom Fakultetu doktorsku disertaciju pod nazivom: **„Analiza i dizajn antena zasnovanih na fraktalnoj geometriji“**, na dalji postupak.

Univerzitet Crne Gore UCG Elektrotehnički fakultet

DEKAN,

Prof. dr Saša Mujović

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UCG
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Broj: 02/1-619
Datum: 26.05.2022

Na osnovu člana 64 Statuta Univerziteta Crne Gore, u vezi sa članom 55 Pravila doktorskih studija, na predlog Komisije za doktorske studije, Vijeće Elektrotehničkog fakulteta u Podgorici, na sjednici od 26.05.2022. godine, donijelo je

O D L U K U

I Utvrđuje se da su ispunjeni uslovi iz Pravila doktorskih studija za dalji rad na doktorskoj disertaciji **„Analiza i dizajn antena zasnovanih na fraktalnoj geometriji“** kandidata MSc **Luke Lazovića.**

II Predlaže se Komisija za ocjenu navedene doktorske disertacije, u sastavu:

1. Dr Branka Jokanović, naučni savetnik, Institut za fiziku, Beograd,
2. Dr Ana Jovanović, redovni profesor Elektrotehničkog fakulteta Univerziteta Crne Gore,
3. Dr Vesna Rubežić, redovni profesor Elektrotehničkog fakulteta Univerziteta Crne Gore.

Komisija iz tačke II ove Odluke podnijeće Izvještaj Vijeću Fakulteta u roku od 45 dana od dana imenovanja.

-VIJEĆE ELEKTROTEHNIČKOG FAKULTETA-

D E K A N,
Prof. dr Saša Mujović

Dostavljeno:
- Senatu,
- Centru za doktorske studije,
- u dosije,
- a/a.

Spisak radova sa rezultatima iz doktorske teze

Vodeći naučni časopisi (SCI/SCIE lista):

1. Lazović, L.; Jokanovic, B.; Rubežić, V.; Radovanovic, M.; Jovanović, A. Fractal Cardioid Slot Antenna for Super Wideband Applications. Electronics 2022, 11, 1043. https://doi.org/10.3390/electronics11071043

Međunarodne konferencije:

1. L. Lazovic, B. Jokanovic, V. Rubezc and A. Jovanovic, (2020): "Uniplanar Ultra-Wideband Cardioid Slot Antenna for Energy Harvesting Application", 2019 27th Telecommunications Forum (TELFOR), pp. 1-4, 2019.
2. Luka Lazović, Branka Jokanovic, Vesna Rubežić and Ana Jovanović (2019): "Printed Ultra-Wideband Cardioid Monopole Antenna for Energy Harvesting Application", TELSIKS 2019, Sebia, Niš, October 23-25, 2019
3. L. Lazović, A. Jovanović i V. Rubežić (2018): „ Optimization of fractal antennas in CST with Chaotic optimization algorithm" Zbornik XXIII Naučno-stručnog skupa Informacione tehnologije IT 2018, Žabljak,
4. L. Lazović, A. Jovanović, B. Lutovac i V. Rubežić (2016): „Primjena teorije grafova za dizajniranje rekonfigurabilnih fraktalnih antena", 24nd Telecommunications forum TELFOR 2016, Belgrade, Serbia, November 25-27. 2016., ISBN: 978-1-5090-4086-5.

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Article

Fractal Cardioid Slot Antenna for Super Wideband Applications

Luka Lazović [1,*], Branka Jokanovic [2,3], Vesna Rubežić [1], Milos Radovanovic [2] and Ana Jovanović [1]

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Abstract: A new geometry for uniplanar, ultra-wideband monopole antenna has been proposed for operations in the 1.8–30 GHz band, thanks to its fractal structure in the form of a cardioid. The antenna has extremely small dimensions at $0.21\lambda \times 0.285\lambda$ at the lowest frequency of 1.8 GHz. A parametric analysis of the influence of certain antenna dimensions on its characteristics was performed in order to achieve the widest possible impedance bandwidth. This antenna is designed for low-cost FR-4 substrate because it is primarily intended for use in broadband energy harvesting and IoT systems, but it is also suitable for applications in communication systems. Simulation results show that the antenna has a reflection coefficient (S_{11}) below -10 dB in the entire 1.8 GHz to 30 GHz frequency range, which covers all existing cellular bands: 3G, 4G, 5G Wi-Fi, ISM, satellite communication and radar bands. The antenna exhibits gains up to 5 dBi.

Keywords: fractal antennas; slot antennas; ultra-wideband antennas; bandwidth dimension ratio

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Citation: Lazović, L.; Jokanovic, B.; Rubežić, V.; Radovanovic, M.; Jovanović, A. Fractal Cardioid Slot Antenna for Super Wideband Applications. *Electronics* **2022**, *11*, 1043. https://doi.org/10.3390/electronics11071043

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1. Introduction

Considering the expansion of mobile communication systems and the forecast that there will be 38 billion connected devices within the IoT and 1.5 billion within 5G by 2025, it is clear that electromagnetic radiated power will be much higher in the future than it is now, as the number of devices connected wirelessly will be greater and it is desirable that antennas for energy harvesting (EH) are designed to cover all bands assigned for those communications. In view of the dependence of the operating frequency on antenna dimensions and the purpose of the antenna, it was concluded that it is optimal to use bands above 1.8 GHz for EH, although the emitted power is higher in the lower bands. Networks such as 3G (UMTS), 4G (LTE) and the future 5G cellular network; ISM (Industrial, Scientific and Medical); and the bands of satellite communications are of particular interest. Electromagnetic energy can be generally collected using rectennas [1–10] (that consist of a single or multiple antennas integrated with a rectifier) or using meta-surfaces [11–13].

Numerous studies of the level of electromagnetic radiation in different cities can be found in the literature. The results presented in [2,3] confirm that bands between 0.3 GHz and 3 GHz could be used for energy harvesting systems and also include the bands planned for 5G and IoT and the bands for satellite communications.

The main requirements for energy harvesting and IoT antennas are the following: simple (planar) structures, low cost, miniaturized without gain degradation and efficiency (electrically small antenna), wide operating bandwidth, wide beamwidth and good broadband matching [4,5]. Printed antennas generally exhibit these characteristics, since they are planar, small in size, have a high degree of reproducibility and since they are easy to make—they do not require complex fabrication processes, and they are compatible with integrated circuitry [6]. However, widespread patch antennas are of the narrowband type.

A large number of energy harvesting antennas can be found in the literature, with good characteristics, but they are mostly designed with narrow bandwidth for single frequency operation, most often with GSM or Wi-Fi [6]. The second group of antennas includes multiband antennas that are designed on expensive dielectric substrates in order to reduce their overall dimensions, which makes them unsuitable for EH applications in IoT and WSN and for integration with other electronics [4,6]. With the advancement of the 5G network, the use of the millimeter frequency bands began, especially the K-band (24.25–27.5 GHz); thus, it is necessary to develop systems for collecting electromagnetic radiation in those bands. It would be optimal to satisfy the stated requirements with the use of only one ultra-broadband antenna. A comparative study of the antennas proposed for EH can be found in [4–9]. Energy harvesting systems in the microwave band can operate with frequencies up to 30 GHz in [10,14,15]. An antenna designed for energy harvesting application on satellites is proposed in [10].

Generally speaking, antennas that are designed for energy harvesting can also be used in communication systems. It is desirable that one antenna can cover all services used in mobile communications [16]. In the case of using ultra-wideband antennas in mobile communications, there is often a need for filtering unwanted frequency bands, i.e., adding notch filters to the antenna itself as in [17–21], which turns this antenna into a multi-resonant one and separates certain bands.

Numerous printed antennas designed on a low-cost FR-4 substrate can be found in the literature. The wideband antenna proposed in [22] has very small dimensions (25 mm $\times$ 25 mm), an operating range of 7.7:1, efficiency of 82% and gain of 5 dBi. It is made on a low-cost FR-4 substrate, but with substrate thicknesses of 1.2 mm, which makes it difficult to integrate with other electronics. The antenna in [23] is designed on FR-4 substrate with a standard thickness of 1.58 mm for frequencies up to 18 GHz achieving a bandwidth ratio of 13:1 at 10 dB return loss, with an electrical area of $0.17\lambda \times 0.37\lambda$.

It is well known that the FR4 substrate has been commonly used for low frequency applications, but it has been recently applied successfully in the design of low-cost antennas at frequencies over 30 GHz, Refs. [24–26]. The antenna proposed in [25] uses the FR-4 substrate, although it is intended for operations up to 37 GHz, with an operating range of 11:1. However, the electrical area of the antenna is pretty large ($0.32\lambda \times 0.34\lambda$).

The simplest method for increasing the antenna's bandwidth without increasing the antenna size is to modify the geometry of the antenna by using fractals [27]. The self-similarity property of fractal geometries causes multiband or broadband behaviors. A comparative study of these antennas can be found in [28].

Fractal antennas with good performances can be found in [29,30], but these antennas do not cover the GSM and UMTS bands, in which a significant amount of EM energy is emitted. Considering the antenna size, the proposed antenna is more than three times smaller in terms of electrical dimensions than the antenna reported in [26].

This paper proposes a novel design of a slot antenna based on nested fractal geometry that exhibits ultra-wideband characteristics. The antenna is designed on inexpensive FR-4 substrate and is fed by coplanar waveguide (CPW) transmission line, which makes it uniplanar, very easy for fabrication and integration with MMICs. The use of fractals in the form of cardioids made it possible to cover all commercial frequency bands from 1.8 to 30 GHz while preserving the small size of the antenna because of the space filling property of the fractals. The proposed antenna can be used in energy harvesting systems, as well as in IoT, WLAN, mobile MIMO and satellite communication systems and radars.

2. Proposed Antenna and Parametric Sweep

Numerous shapes of fractal antennas can be found in the literature, while those that satisfy the shapes of mathematical curves are particularly important.

The antenna structure presented here is based on a slot in the form of more self-similar nested cardioids. The standard parametric mathematical expression for cardioid is the following [31,32]:

$$\begin{aligned} x(\varphi) &= a\cos\varphi(1-\cos\varphi) \\ y(\varphi) &= a\sin\varphi(1-\cos\varphi) \\ 0 &\le \varphi \le 2\pi \end{aligned} \quad (1)$$

where the parameter a scales the cardioids to the desired dimension. The proposed antenna has three cardioids that define its structure. Their scaling parameters, according to Equation (1), are a_1, a_2 and a_3, as seen in Figure 1.

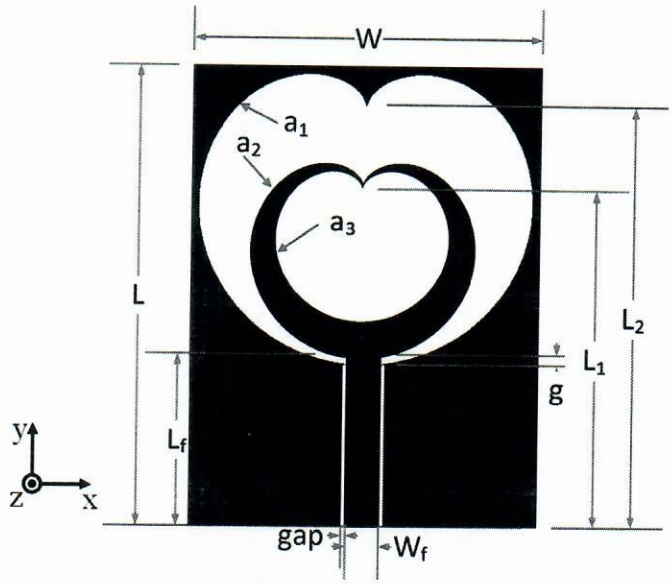

Figure 1. The geometry of the proposed fractal antenna. The metal is shown in black. Relevant dimensions of the antenna are as follows: W = 35.1 mm, L = 47.5 mm, gap = 0.25 mm, W_f = 2.85 mm, L_f = 16.4 mm, g = 0.40 mm, L_1= 34.45 mm (distance from the cardioid center), L_2 = 42.43 mm, a_1 = 6.6, a_2 = 4.68 and a_3 = 3.4.

The fractal shapes are characterized by two parameters: the iteration order (IO) and iteration factor (IF) [23]. The iteration order represents the number of fractal iterations, while the iteration factor represents the ratio of the dimensions of the second and first iterations of fractals. The iteration factor is always less than one because the last fractal dimension is always smaller than the previous one due to nested fractal geometry. Generally, in the majority of the proposed fractal antennas, the IF is the same for each iteration. However, in this paper, we propose a fractal antenna where the IF changes for each subsequent iteration. In this case, we can define IF_0, which represents the ratio between a_2 and a_1 and IF_1, which represents the ratio between a_3 and a_2. The IF for the zeroth iteration of the realized antenna is $IF_0 = a_2/a_1 = 0.68$ and the IF for the first iteration is $IF_1 = a_3/a_2 = 0.75$. It provides additional flexibility in antenna design.

The antenna is designed for the FR-4 substrate of dielectric constant ε_r = 4.3 and $tan\delta$ = 0.025. The thickness of the substrate is 1.58 mm and the thickness of copper metallization is 0.018 mm. Parametric analysis was performed in order to obtain the maximum antenna impedance bandwidth; thus, the antenna can be used in energy harvesting applications without a lossy matching circuit between the antenna and detector. Simulations are performed in the time domain-based CST solver.

The overall dimensions of the antenna are 35 mm × 47 mm × 1.61 mm, which classifies this antenna into a group of electrically small antennas [33]. The geometry of the proposed antenna is shown in Figure 1.

2.1. Effects of Different Antenna Iteration Orders

Figure 2 shows the procedure for constructing a cardioid fractal slot antenna with different iteration orders (and similarly to a majority of fractals with the same IF). The generator shape for this fractal antenna is a cardioid described by Equation (1). The starting point for this antenna is the zeroth iteration fractal, i.e., the cardioid antenna shown on Figure 2a. Additionally, this figure shows the generation of the fractal structure in which each iteration has the same iteration factor IF = 0.68 ($IF = a_2/a_1 = a_3/a_2 = a_4/a_3 = a_5/a_4$).

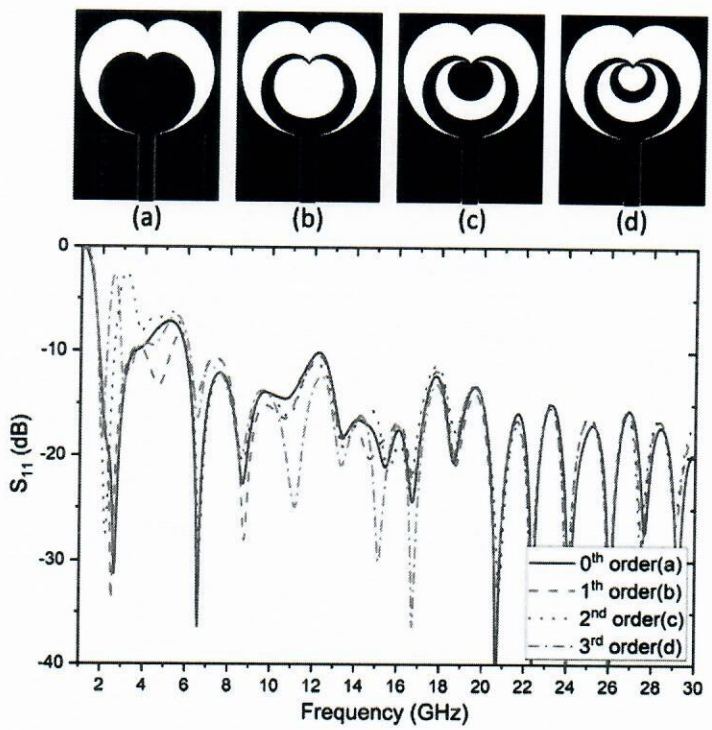

Figure 2. Simulated reflection coefficients for the fractal antenna geometries with different iteration orders. (**a**) 0th iteration order; (**b**) 1th iteration order; (**c**) 2nd iteration order; (**d**) 3rd iteration order.

When examining the reflection coefficient of the antenna with zeroth iteration order and the antenna with the first iteration order seen in Figure 2b, it is observable that the cardioid in Figure 2b has a wider operating range. If the condition for the antenna operating range is taken to be $S_{11} < -10$ dB, in the case of the zeroth iteration, this condition is fulfilled in two frequency bands: 1.8–3.5 GHz and 5.9–30 GHz, with the antennas having second and third iteration orders where the condition is met in a narrower band 1.8–2.57 GHz. The best characteristic in terms of broadband operation was obtained with a cardioid with the first iteration order (Figure 2c), whereas the S_{11} characteristic deteriorates by further increasing the iteration order, as is the case of a cardioid with the second and third iteration order (Figure 2d).

By analyzing the results of simulations as well as fractal geometry that can be found in the literature, it was decided that the proposed antenna should be designed using fractal geometry, which changes the iteration factor in each subsequent iteration. In this manner, greater flexibility in design is achieved.

2.2. Effects of the Iteration Factor

When designing the antenna, it was determined that the parameter a_1 and the overall dimensions of the antenna ($W \times L$) affect the position of the lowest resonant frequency where $S_{11} < -10$ dB. Parameter a_1 is set at 6.6 so that the lowest frequency would be 1.8 GHz.

Furthermore, we can observe the effect of changing the iteration factor on antenna performance. IF_1 when defined as the ratio of a_3/a_2 can be changed in two ways—either by changing a_2 while a_3 remains constant or by changing a_3 while a_2 remains constant.

2.2.1. Effects of the Parameter a_2

The influence of dimension a_2, i.e., different values of $IF_1 = a_3/a_2$, on the S_{11} parameters when the parameters $a_1 = 6.6$ and $a_3 = 3.4$ are constant, is shown in Figure 3.

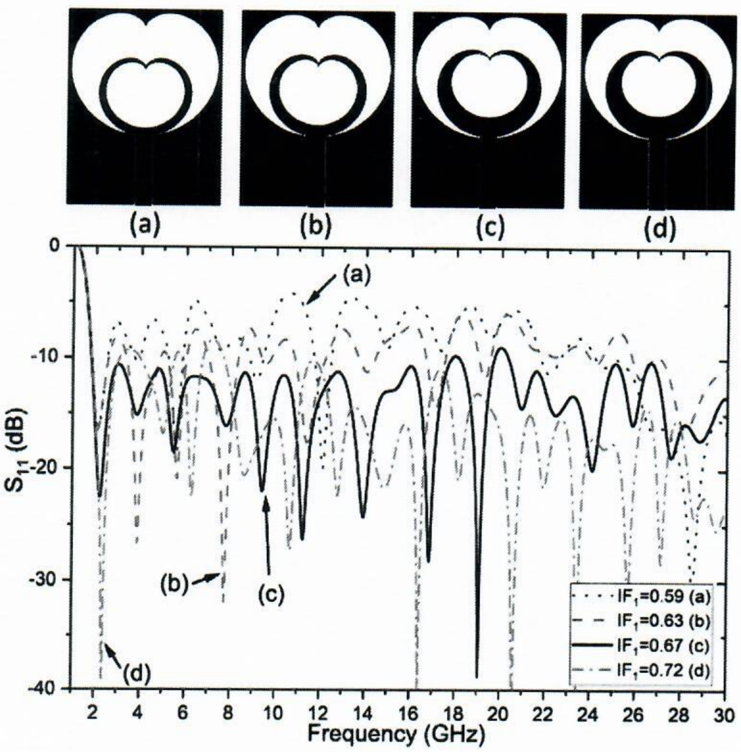

Figure 3. The simulated reflection coefficients of the first order fractal antenna for different iteration factors $IF_1 = a_3/a_2$ obtained by changing the value of parameter a_2: (**a**) $a_2 = 3.91$, (**b**) $a_2 = 4.18$, (**c**) $a_2 = 4.45$ and (**d**) $a_2 = 4.72$. The parameters are $a_1 = 6.6$ and $a_3 = 3.4$.

A change in the value of parameter a_2 has a significant impact on the resonant frequency position above 2 GHz and the S_{11} level throughout the entire band. The best results in this parameter range are achieved with $a_2 = 4.45$ ($IF_1 = 0.67$). Such a big influence of parameter a_2 on S_{11} is characteristic of the antenna, and it can be explained by the fact that, by changing a_2, two iteration factors are changing at the same time: $IF_0 = a_2/a_1$ and $IF_1 = a_3/a_2$.

2.2.2. Effects of the Parameter a_3

In further analysis, the parameters a_1 and a_2 are kept constant while the a_3 parameter was changed until the desired criteria were met. The influences of dimension a_3, i.e., different $IF_1 = a_3/a_2$, on the S_{11} parameter when the parameters are set at $a_1 = 6.6$ and $a_2 = 4.55$ are constant, and they are shown in Figure 4.

Figure 4 shows that, in this scenario, for the iteration factor $IF_1 = 0.72$, the S_{11} characteristic is below -10 dB in the widest frequency range. Based on the results shown in Figures 2–4, a noticeable advantage of the different IFs for each subsequent iteration can be observed. The proposed method increases the flexibility of the design and the ability to meet more antenna requirements than in case with a fixed IF. In this manner, the antenna characteristics can be even further improved.

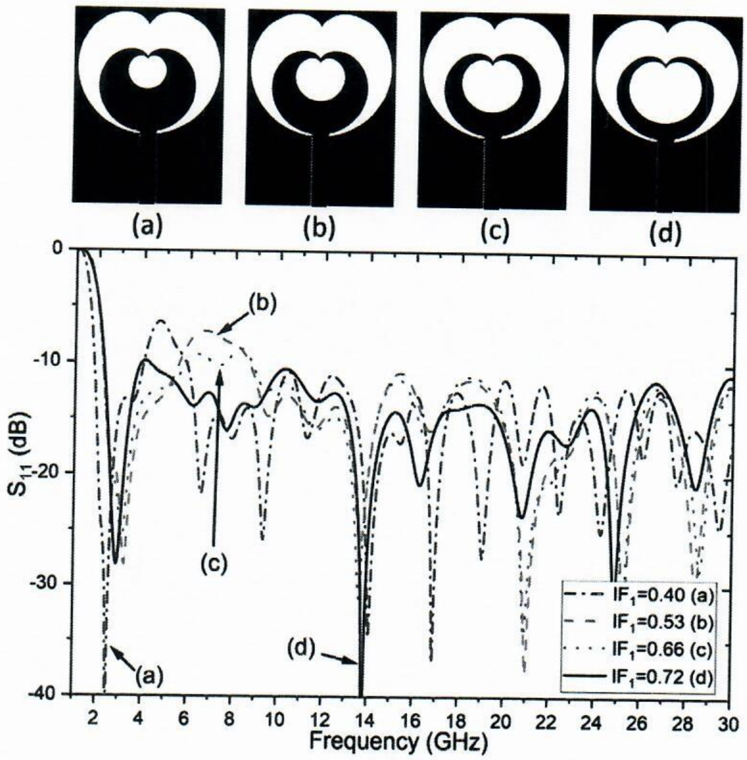

Figure 4. The simulated reflection coefficients of the first order fractal antenna for different iteration factors $IF_1 = a_3/a_2$ obtained by changing the value of parameter a_3 when $a_1 = 6.6$ and $a_2 = 4.55$: (**a**) $a_3 = 3.64$, (**b**) $a_3 = 4.82$, (**c**) $a_3 = 6.06$ and (**d**) $a_3 = 6.55$.

2.3. *Effects of the Parameter g*

The influence of dimension g at the point where the CPW line supplies the cardioid, on the reflection coefficient, is shown in Figure 5. It can be observed that the parameter g has a significant influence on the reflection coefficient level. The widest bandwidth characteristic is obtained when $g = 0.4$ mm, and further increases in the value of g considerably deteriorates the reflection coefficient in the entire operating band.

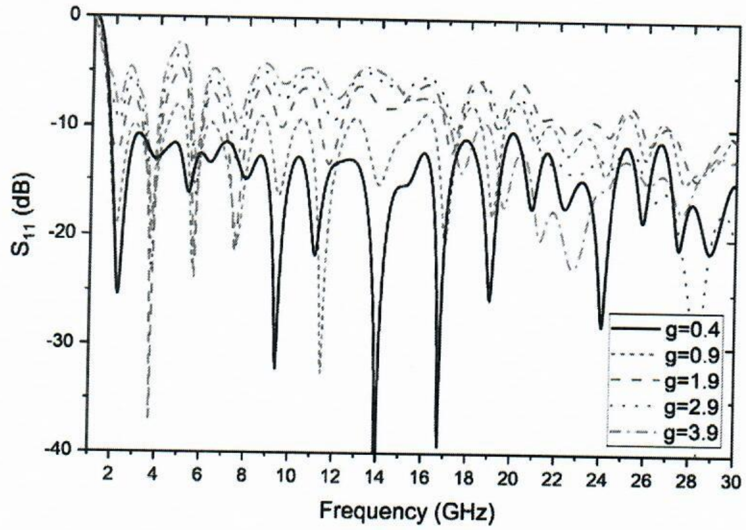

Figure 5. The simulated reflection coefficients for different values of distance *g*.

2.4. Characteristics of the Proposed Antenna

The simulated values of real and imaginary parts of the impedance of optimized antennas (Figure 1) are shown in Figure 6.

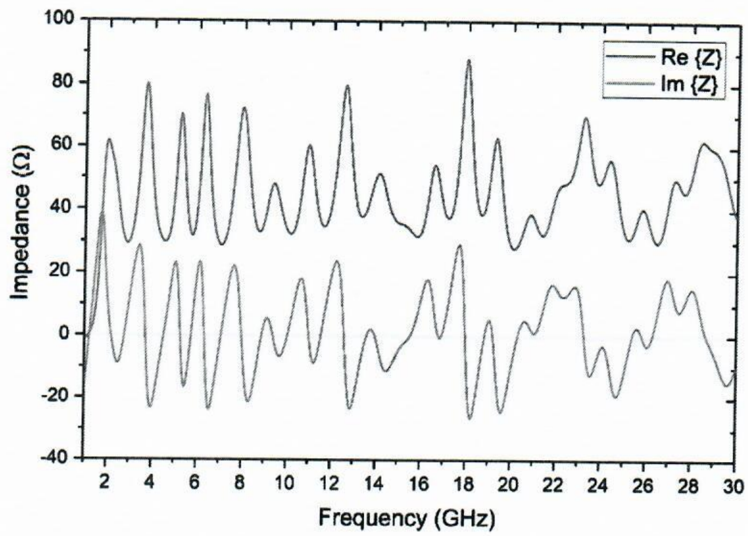

Figure 6. Simulated impedance of the proposed antenna.

The results show a very narrow range of variation of the real part of the impedance of only 28–87 Ω, which is very useful for wideband energy harvesting applications.

The current density distribution at the first six antenna resonant frequencies, 2.1 GHz, 3.7 GHz, 5.2 GHz, 6.3 GHz, 8 GHz and 9.3 GHz, are shown in Figure 7.

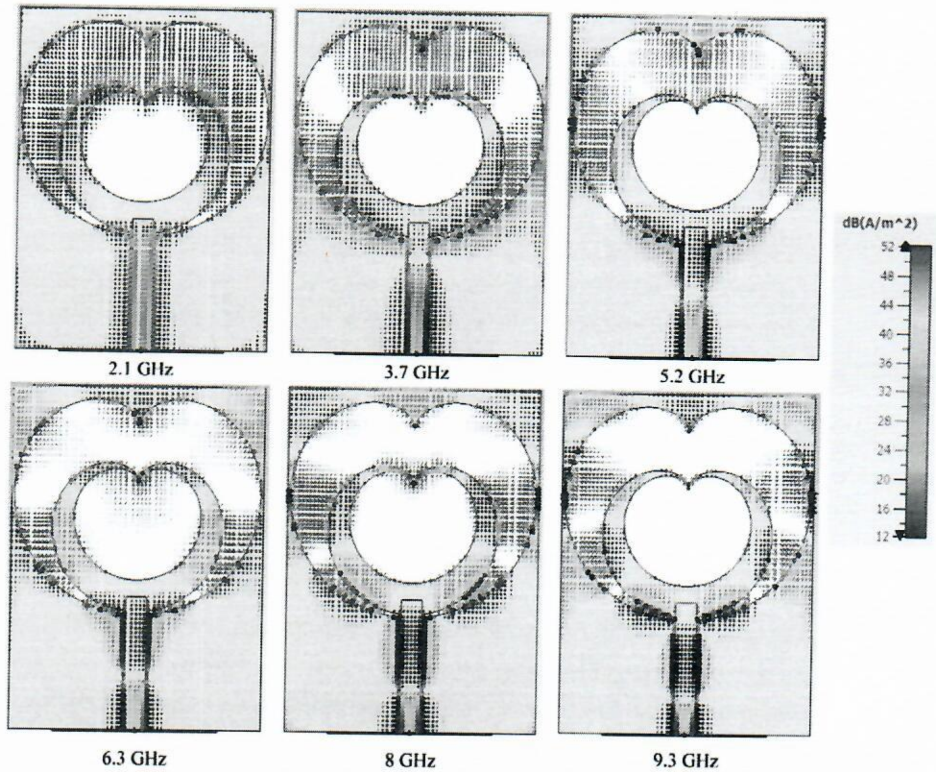

Figure 7. Current density distribution over the antenna surface at a few resonant frequencies.

Simulated radiation patterns of the proposed antenna in the E-planes and H-planes are provided in the following frequencies: 1.8 GHz, 2.2 GHz, 2.4 GHz, 3.4 GHz, 5.8 GHz, 10 GHz, 13 GHz, 17 GHz, 19 GHz, 24 GHz, 28 GHz and 30 GHz. They are shown in Figure 8.

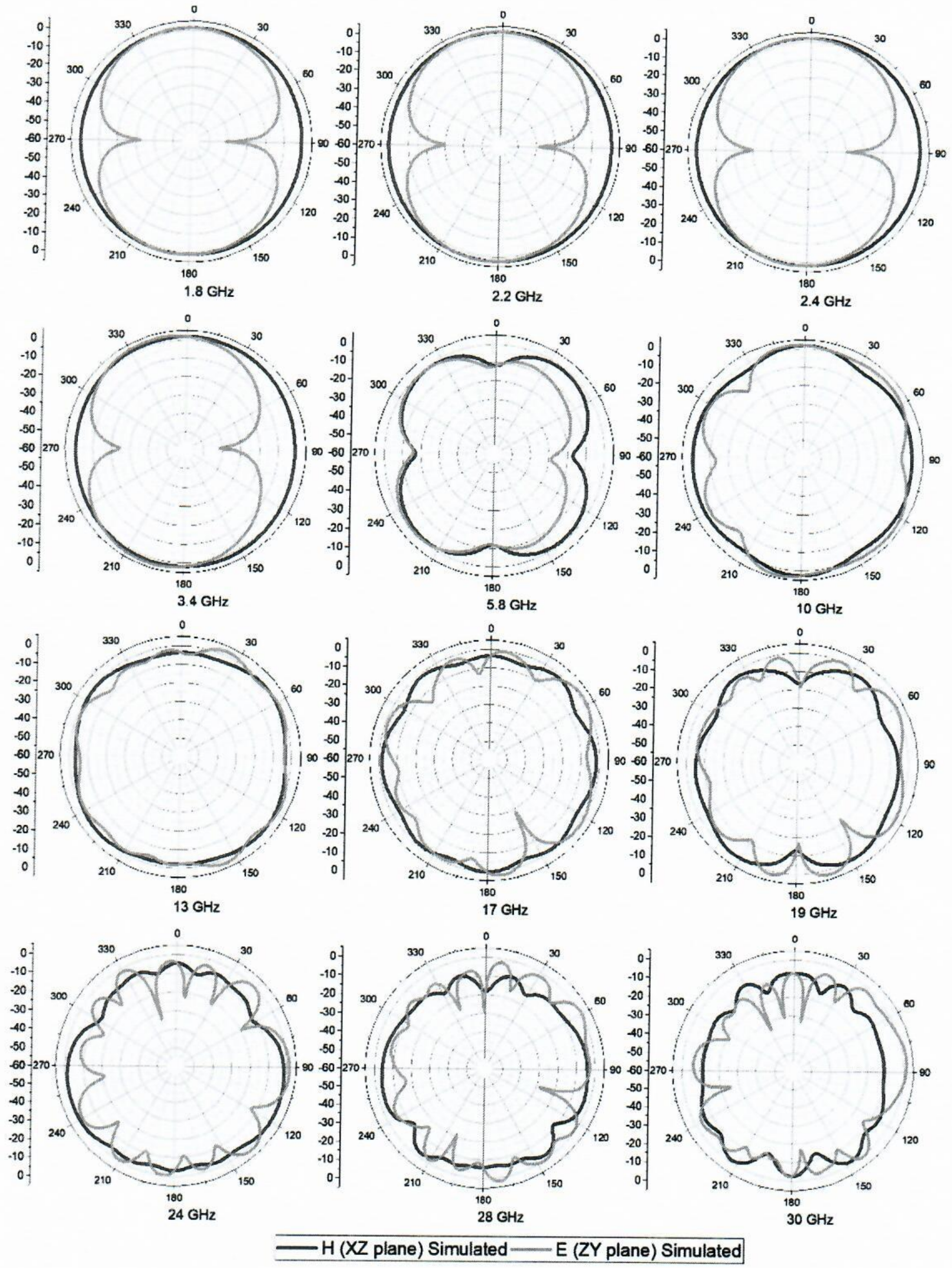

Figure 8. Simulated radiation patterns of the antenna in the E-plane and H-plane.

Simulated 3D radiation patterns of the proposed antenna on frequencies 1.8 GHz, 2.2 GHz, 2.4 GHz, 3.4 GHz, 5.8 GHz and 10 GHz in the logaritmic scale are shown in Figure 9.

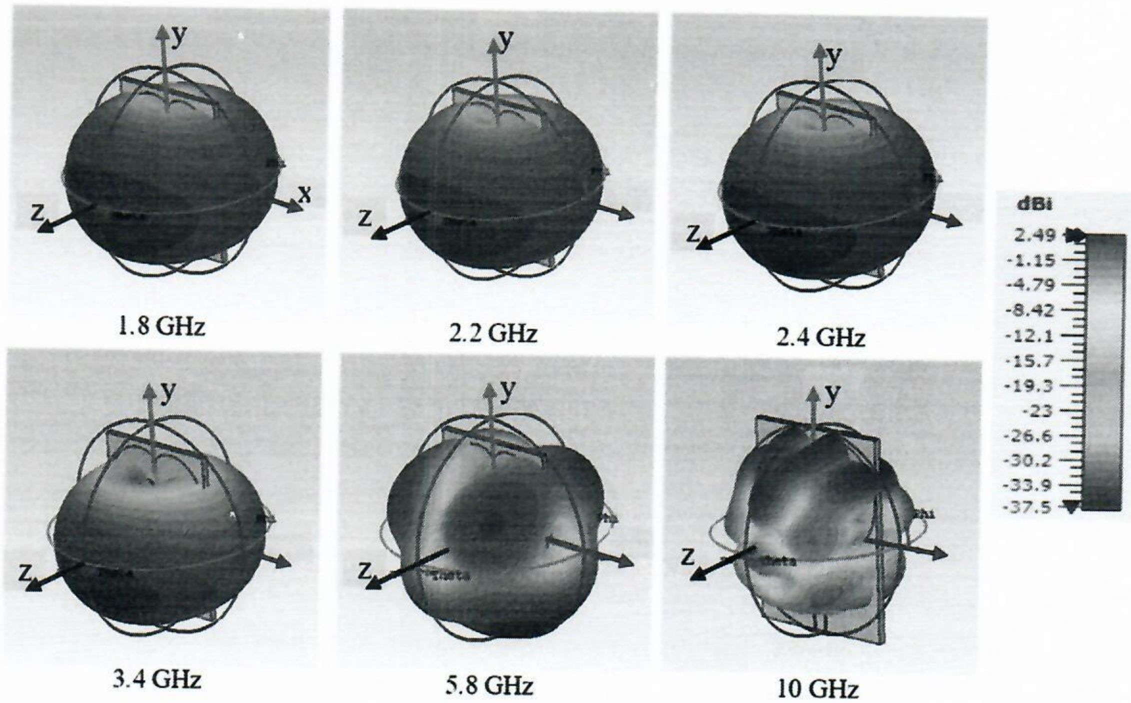

Figure 9. Three-dimensional representation of the simulated radiation patterns.

3. Experimental Results and Discussion

The antenna is manufactured using a simple photolithographic process, with a small deviation from the desired dimensions. Figure 10. shows the produced antenna on an FR-4 substrate with a coaxial SMA connector [34] at the input of the CPW line, which is declared for frequencies up to 27 GHz.

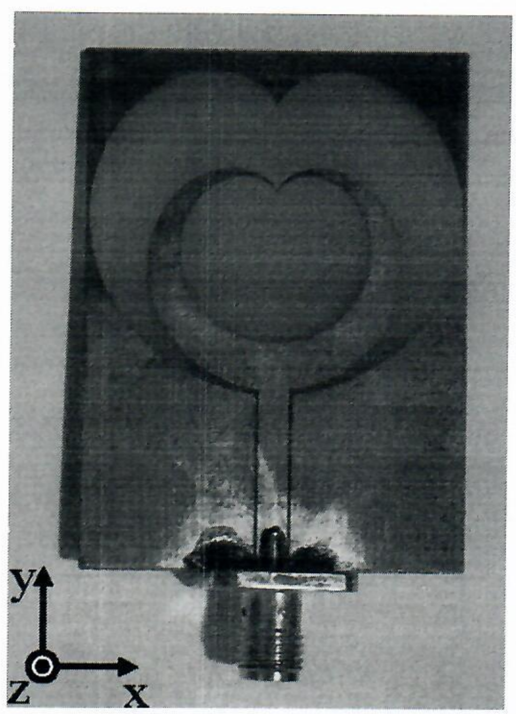

Figure 10. Realized fractal antenna in the form of a cardioid with overall dimensions of 35 mm × 47 mm.

The antenna was measured using a vector network analyzer ANRITSU MS4647A. The reflection on the coaxial port of the antenna was obtained directly from the measurement results of the network analyzer. The maximum gain *GR* of the receiving antenna is obtained based on the Friis formula for the attenuation of free space:

$$G_R = 20log_{10}d + 20log_{10}f + 20log_{10}4\pi/c - G_T - FSPL \quad (2)$$

where *FSPL* denotes free space attenuation; *d* denotes distance in meters; *f* denotes frequency; *c* denotes the speed of light in a vacuum; *GT* denotes the gain of the transmitting antenna; and *GR* denotes the gain of the receiving antenna. A ridge-horn antenna was used as a transmitting antenna.

The measured and simulated S_{11} parameters are shown in Figure 11.

Some disagreement between measured and simulated results occur due to inaccuracies in manufacturing and because antenna simulations are performed without connectors. Moreover, the electromagnetic properties of a low-cost FR-4 laminate are not strictly controlled and may differ from one laminate board to another.

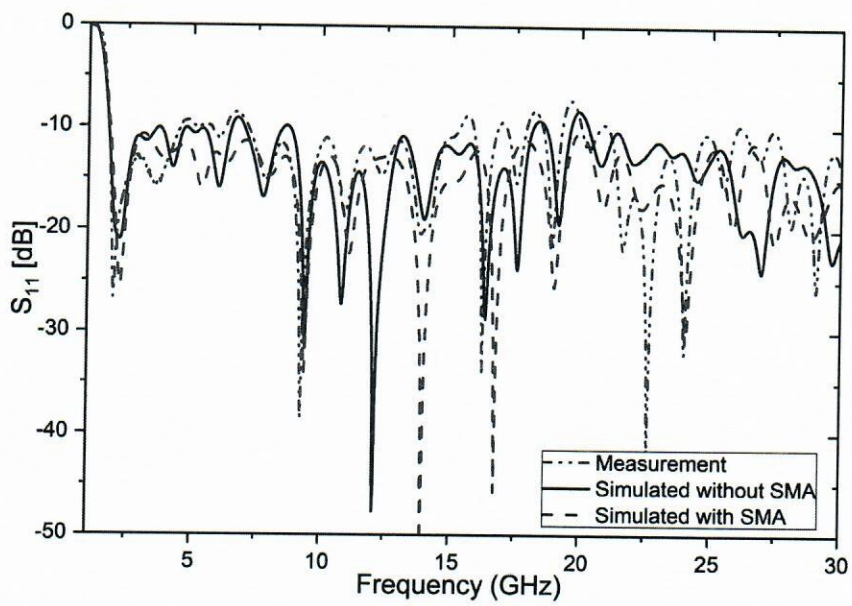

Figure 11. Comparison of the measured and simulated reflection coefficients of the antenna with and without SMA connector.

In order to remove doubt about the influence of the SMA connector on an antenna reflection coefficient above 27 GHz, the simulation was performed with an ideal excitation (waveguide port) and then with an SMA connector [34]. It can be observed from Figure 11 that there are differences in the reflection coefficient above 20 GHz but the reflection coefficient is below −10 dB with and without the connector. It is clear that the SMA connector, in this project, can be used up to 30 GHz without influencing the improvement of the reflection coefficient.

Figure 12 shows the results of measurements and simulations of the gain calculated by expression (2). The gain was only measured up to 6 GHz because the transmitting antenna is declared in that band.

The proposed antenna is compared with previously reported super wideband (SWB) antennas on FR-4 substrates in terms of operating bandwidth (BW), electrical dimensions and bandwidth dimension ratio (BDR). The results are shown in Table 1. The bandwidth dimension ratio indicates how large the operating bandwidth is as a percentage per antenna electrical area unit [23]:

$$BDR = \frac{BW_{\%}}{L_{f_{low}} \times W_{f_{low}}} \quad (3)$$

where $L_{f_{low}}$ represents the electrical length and $W_{f_{low}}$ represents the electrical width of the antenna calculated at the lower-end of operating band that meets the -10 dB return loss and $BW_{\%}$ represents bandwidth in percentage calculated by the following formula:

$$BW_{\%} = 2\left(f_{high} - f_{low}\right) / \left(f_{high} + f_{low}\right) \cdot 100\% \quad (4)$$

where f_{low} and f_{high} represent the lower and higher frequencies of operating bands, respectively. A larger BDR indicates that the designed antenna is smaller in dimension and wider in bandwidth.

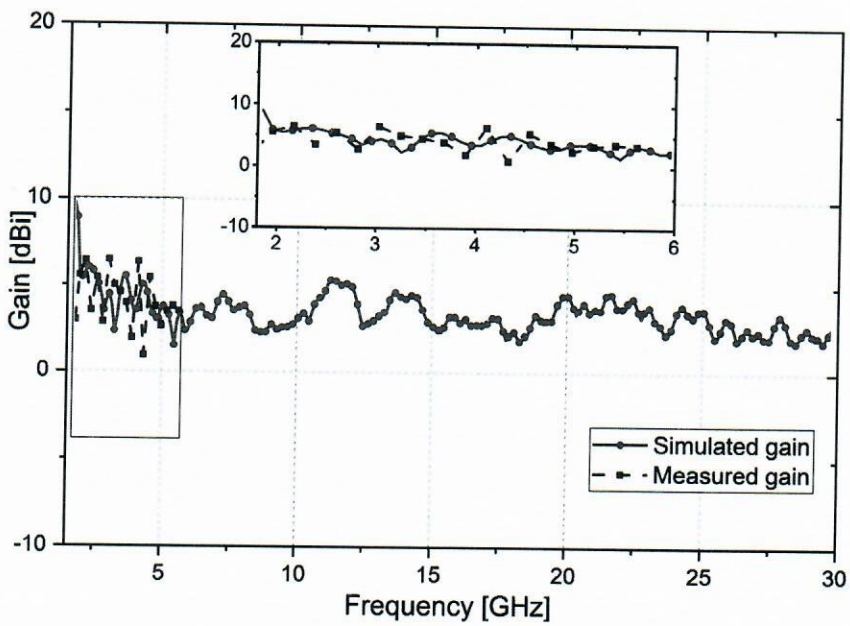

Figure 12. Measured and simulated gain of the proposed antenna.

Table 1. Comparison of the SWB antenna structures fabricated on FR-4 substrates in terms of various parameters.

Reference	Freq. Range (GHz)	BW:1	BW %	Electrical Dimensions [1]	BDR
[23]	1.4–18.8	13.0:1	172%	0.17 λ × 0.37 λ	2762.7
[25]	3.4–37.4	11.0:1	167%	0.32 λ × 0.34 λ	1544.7
[29]	2.9–10.7	3.6:1	115%	0.16 λ × 0.29 λ	2406.9
[26]	3–35	11.6:1	168%	0.38 λ × 0.55 λ	805.84
[35]	2.2–22.1	9.8:1	163%	0.30 λ × 0.23 λ	2393.7
[36]	2.4–24.3	10.1:1	164%	0.18 λ × 0.33 λ	2718.1
[37]	2.9–18	6.2:1	144%	0.29 λ × 0.29 λ	1718.2
[38]	3–11.2	3.7:1	115%	0.22 λ × 0.24 λ	2187.4
Proposed	1.8–30	**16.9:1**	**178%**	0.21 λ × 0.28 λ	**3062.1**

[1] Electrical dimensions are calculated relative to the lowest frequency in the band.

Figure 13 shows a comparison of simulated and measured radiation patterns in the E-plane and H-plane at the following frequencies: 1.8; 2.2; 2.4; 3.4, 5.8 and 10 GHz.

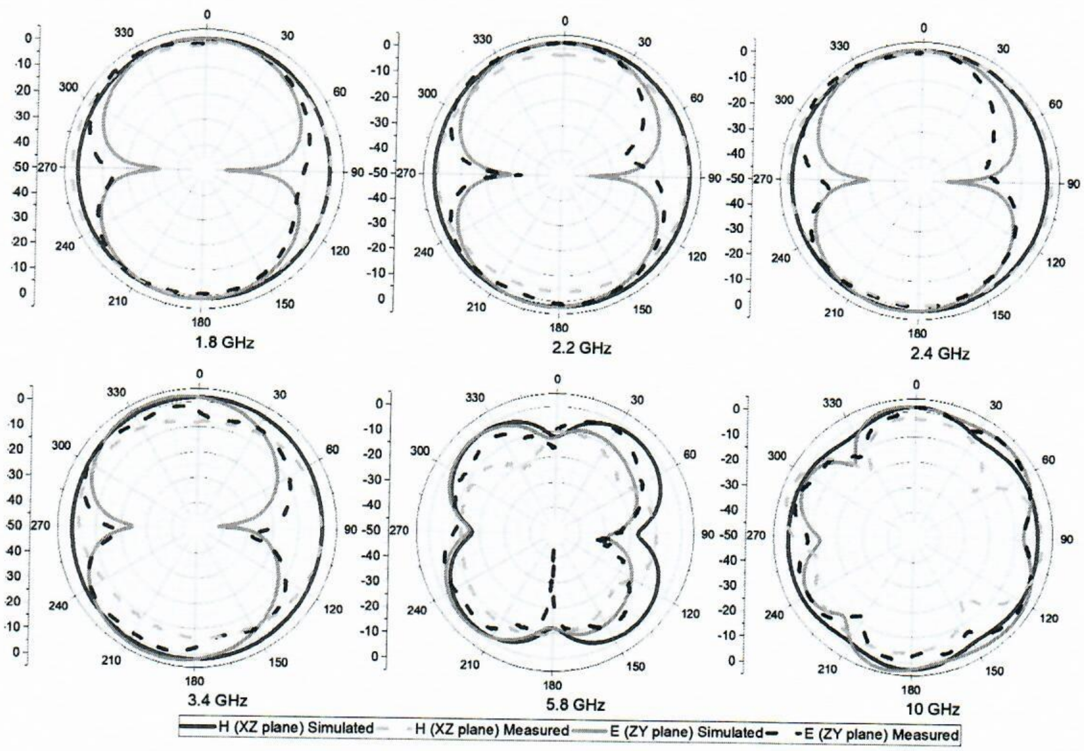

Figure 13. Measured and simulated radiation patterns in the E-plane and H-plane.

Based on the measurement results shown in Figure 13, a pretty good match of the simulated and measured radiation patterns can be noted. All measurements of the antenna radiation patterns are performed in free space, since the anechoic chamber is not available. Some discrepancies between measured and simulated results can be explained by this fact. It can be observed that the proposed antenna exhibits almost omnidirectional radiation patterns up to 5.8 GHz, which is wider than one octave (3.2:1). It is not possible to increase radiation pattern's bandwidth without decreasing the impedance bandwidth. The design of this antenna was devoted to obtaining the maximum antenna impedance bandwidth because its primary purpose was energy harvesting. The one method to improve antenna radiation patterns at higher frequencies is to reduce antenna dimensions, but the impedance bandwidth will be reduced at low frequencies.

4. Conclusions

The original design of a broadband slot antenna is shown, which is suitable for mass and cheap production and can be used either as a separate device or integrated with other subdevices of a telecommunication system in the frequency range of 1.8–30 GHz (16:1). A parametric analysis was performed to obtain the widest possible impedance bandwidth in order to avoid a lossy matching circuit between the antenna and detector in energy harvesting systems. Simulation results show that, by using fractal geometry and the cardioid shape, the desired impedance matching, gain and efficiency are all achieved in ultra-wideband frequency ranges.

The antenna has small dimensions at only 35 mm × 47 mm ($0.21\lambda \times 0.285\lambda$) and exhibits a maximum BDR (bandwidth dimension ratio) of 3062 compared to the ones published in the literature so far. A larger BDR indicates that the designed antenna is smaller in dimension and wider in bandwidth. Simulated and measured results show that the antenna has a reflection coefficient, S11, below −10 dB in the entire 1.8 GHz to 30 GHz frequency range. The antenna exhibits gains up to 5 dBi. The measured radiation patterns on frequencies 1.8, 2.2, 2.4, 3.4, 5.8 and 10 GHz are presented.

The antenna is uniplanar and does not require any complicated photolithography procedures during fabrication. It is realized on a cheap FR-4 substrate and is fed by a CPW line; thus, it is very suitable for integration with diodes and transistors. This is very important since it is primarily intended for the broadband harvesting of electromagnetic energy and its conversion in direct currents for biasing low-power sensor networks. Antenna impedances have very small variations from 28 to 87 Ω, which is very convenient for use in recetennas without matching circuits. In addition to this basic purpose, the antenna can be used as a transceiver antenna for 3G, LTE, 5G, WLAN, RFID, Bluetooth, ISM, satellite communication and radars.

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Biografija

Lazović Luka je rođen 7.10.1987. godine u Nikšiću. Osnovu školu i Gimnaziju je završio u Nikšiću. Elektrotehnički fakultet u Podgorici završio je 2010. godine, odbranom diplomskog rada „Optimizacija potrošnje snage u integrisanim Charge pump kolima". Magistarsku tezu pod nazivom „Analiza performansi adaptivnih algoritama za sintezu dijagrama zračenja planarnih antenskih nizova" odbranio je 18.06.2015. godine. Doktorske studije na odsjeku za Mikrotalasnu tehniku upisao je 2015 godine.

Radni angažman započeo je u firmi „Ening" DOO Nikšić 2010. godine na poslovima inženjeringa i projektovanja automatske regulacije termo-tehničkih sistema kao i BMS (Building Monitoring System) sistema. U Elektroprivredi Crne Gore radi od 2012. godine u Funkcionalnoj Cjelini Distribucija. Angažovan je na projektu unapređenja sistema mjerenja u distributivnom sistemu.

Kao saradnik u nastavi na Elektrotehničkom fakultetu u Podgorici, Luka je angažovan 2014. godine na većem broju predmeta iz oblasti Opšte elektrotehnike i to: Osnovi elektrotehnike II, Elektromagnetika, Prostiranje i zračenje elektromagnetnih talasa, Mikrotalasne antene, Mikrotalasna tehnika, Mikrotalasna kola i mjerenja, Smart antene, Nelinearna kola i Električne instalacije i osvjetljenje. Oblasti naučnog interesovanja su: Pametni antenski sistemi, algoritmi za sintezu dijagrama zračenja, antene za 5G sisteme i prostiranje i zračenje elektromagnetnih talasa.

Autor je više radova objavljenih u međunarodnim i domaćim časopisima kao i na međunarodnim i domaćim konferencijama. Recenzent je više radova u prestižnim časopisima AEU i COMPEL. Takođe, recenzent je više radova na konferencijijama IT i ETRAN. Član je profesionalnog udruženja IEEE sekcija za Mikrotalasnu tehniku i Antene i prostiranje.

Luka je bio angažovan na prvom Centru izvrsnosti u Crnoj Gori (BIO-ICT). Član je tima Laboratorije akreditovane za mjerenje elektromagnetnih emisija. Angažovan je na bilateralnom projektu „5G-RECTenna" u saradnji sa Institutom za fiziku u Beogradu.

Govori engleski jezik.

Kompletna bibliografija

Master teza:

L. Lazovic: „Analiza performansi adaptivnih algoritama za sintezu dijagrama zračenja planarnih antenskih nizova“, *MSc Thesis,* Univerzitet Crne Gore, Podgorica, 2015. godine.

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БРАНКА ЈОКАНОВИЋ, редовни члан Академије инжењерских наука Србије (АИНС) од 2018. године, рођена је 18.08.1953. у Ужицу где је завршила основну школу и гимназију као ђак генерације и носилац Вукове дипломе. Дипломирала је 1977. године на Електротехничком факултету у Београду а магистрирала и докторирала на истом факултету из области микроталасних мешача и балуна 1988, односно 1999. године. У звање научног саветника изабрана је 2008. године. Од 1978. до 2009. године ради у Институту за примењену физику, данашњи Институт ИМТЕЛ, на истраживачким и развојним пројектима из области микроталасне и милиметарске технике. Од 2003. године је на месту саветника директора за науку. Октобра 2009. године прелази у Институт за физику, Центар за фотонику где је основала Лабораторију за метаматеријале која се бави истраживањем и применом вештачких електомагнетских структура. Б. Јокановић је била гостујући истраживач на *University of Virginia, Semicondactor Device Laboratory, Charlottesville, USA*, 1989. године, а 2000. године је на постдокторском усавршавању на *Department for Electrical and Electronic Engineering, University of Stellenbosch, South Africa*. Радила је као гостујући научник по позиву 2008. године у *Heart Sensing Laboratory, Department of Electrical Engineering, University of Hawai'i, USA,* затим 2009, 2010. и 2011. на *Department for Electrical and Electronic Engineering, University of Stellenbosch, South Africa*.

У периоду 1991.-2000. године руководила је развојем и производњом првог домаћег милиметарског линка на 23 GHz који је добио атест ЗЈ ПТТ и ушао у серијску производњу. Захваљујући овом линку Институт ИМТЕЛ се афирмисао на тржишту радио-релејних уређаја. Била је руководилац на више пројеката за ЈНА као и на пројектима које је финансирало Министарство за науку и технолошки развој Србије. Објавила је преко 100 радова у међународним часописима и конференцијама, 3 поглавља у међународним монографијама, 1 монографију националног значаја и преко 80 радова у домаћим часописима и конференцијама. Сви публиковани радови базирани су на оригиналним склоповима развијеним за конкретне радарске и комуникационе уређаје. Радови Б. Јокановић су до сада цитирани 1094 (Google Scholar) пута.

Научна активност Б. Јокановић обухвата истраживања у области радио-комуникација на микроталасном и милиметарском опсеgu, посебно микроталасних мешача, директних QPSK модулатора, широкопојасних прелаза са симетричног на несиметричан вод, као и минијатурних филтара и диплексера. Посебан допринос је дала у пројектовању мешача са потискивањем симетричне учестаности који представљају кључни склоп микроталасних примопредајника. Ови мешачи су уграђени у пешадијске радаре, осматрачке системе и беспилотну летилицу који су развијени у Институту за примењену физику, као и у све радио-релејне уређаје Института ИМТЕЛ. Б. Јокановић је коаутор нове класе минијатурних широкопојасних прелаза са балансног на небалансни вод (балун) под називом **Двоструки-Y балун**. Такође је 2001. године развила интегрисани микроталасни примопредајник са директним QPSK модулатором на 23 GHz који је уграђен у више стотина радио-релејних уређаја РРУ23А Института ИМТЕЛ. Према нашем сазнању ИМТЕЛ-ови линкови су први у свету код којих је у серијској производњи примењена директна модулација предајног сигнала на микроталасном опсегу, тако да није потребан up-конвертор и филтар. Од 2005. године Б. Јокановић се бави електромагнетским метаматеријалима и њиховом применом у минијатуризацији реконфигурабилних филтара и антена.

Б. Јокановић је ко-оснивач Југословенског *IEEE MTT-S Chapter*-а 1989. године. Такође је 1991. године организовала прву IEEE конференцију у Југославији: *The First Scientific Meeting of Microwaves in Medicine'91*. Од 1989.-2000. године је председник Југословенског *IEEE MTT-S Chapter*-а, а 1991. године је изабрана за члана Административног комитета *IEEE MTT-Society* као представник Региона 8. Године 1994. је иницирала оснивање Југословенског удружења за микроталасну технику и технологију-YU MTT и била његов председник до 2000. године. Исте године је покренула једини национални часопис за микроталасну технику и технологију који излази на енглеском језику: *Microwave Review* и била његов уредник у периоду од 1994.-2002. године.

Б. Јокановић је за свој рад добила следећа признања: награду Института ИМТЕЛ за научни допринос 1996. године, *IEEE Third Millenium Medal 2000*. године, награду Југословенског удружења за микроталасну технику и технологију-YU MTT 2005. године, награду Проф. Александар Маринчић за најбољи рад публикован 2013, награду Проф. Илија Стојановић за најбољи рад објављен 2015. године, као и више награда за најбољи рад на Антенској и Микроталасној секцији ЕТРАН-а.

Бранка С. Јокановић

БИБЛИОГРАФИЈА*

I. НАУЧНО-ИСТРАЖИВАЧКИ РЕЗУЛТАТИ

M10 – Монографије и монографске студије

M13 – Поглавље у књизи M11

1. A. Nesic, V. Trifunovic, **B. Jokanovic**, "Highly Efficient Two-Dimensional Printed Antenna Array with a New Feeding Network", in the book edited by Peter Clarricoats, Advanced Antenna Technology, 1987, Volume 2, Microwave Exhibitions and Publishers Ltd., p. 67-71
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M20 – Радови међународног значаја

M21 – Рад у врхунском међународном часопису

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1. **B. Jokanovic**, V. Trifunovic, "Ku Band SSB Mixer", *Microwave Journal*, June 1989, pp.153-158, Vol. 27, No. 6, pp. 554-556, June., ISSN 0192-6225, **Impact Factor:** 0.258, Broj citata: 1 (Google Scholar).
2. B. Jokanovic, V. Trifunovic, "Double-Y Baluns for MMICs and Wireless Applications", *Microwave Journal*, January 1998, pp. 70-92, ISSN 0192-6225, **Impact Factor:** 0.258, Broj citata: 14 (Google Scholar).
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5. D. Markovic, **B. Jokanovic,** J. Kiriazi and V. Lubecke: "Implementation of Rigorous EM Simulations for Design and production of Narrow Band Waveguide Diplexer", *Microwave and Optical Technology Letters*, Vol. 50. No. 4, Apr. 2008, pp. 1032-1036, Doi: 0.1002/mop.23277, **Impact Factor:** 0.731, Broj citata: 0 (Google Scholar).
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8. V Milosevic, R Bojanic, **B Jokanovic**, "Analytical modeling of antisymmetric split-ring resonators coupled with transmission line", *International Journal of Microwave and Wirelwss Technologies, Vol.* 11, Issue 4, pp. 359-367, 2019, Doi: 10.1017/SI759078719000308, **Impact Factor:** 1.064, Broj citata: 1 (Google Scholar).

M24 – Рад у часопису међународног значаја

1. **B. Jokanovic**, A. Marincic and B. Kolundžija: "Theoretical and Experimental Investigation of Parasitic Effects in Double-Y Baluns", *Facta Universitatis (Niš), Ser. Elec. Energ.* Vol.13, No.2, August 2000, pp. 219-230, Broj citata: 3 (Google Scholar).
2. N. Boskovic, **B. Jokanovic**, A. Nesic, "Frequency scanning antenna arrays with pentagonal dipoles of different impedances", *Serbian Journal of Electrical Engineering,* Vol.12, No.1, August 2000, pp. 219-230, Doi: 10.2298/SJEE1501098B, Broj citata: 2 (Google Scholar).

M40 – Националне монографије

M42 – Монографија националног значаја

1. **Dr Branka Jokanović**, Velimir Trifunović: "Dvostruki-Y baluni", Zadužbina Andrejević, Edicija Posebna izdanja, Beograd, 2002, ISBN 86-7244-246-6.

M70 – Магистарска и докторска теза

M71 – Магистарски рад

1. B. Jokanović, "Projektovanje i realizacija mikrostrip mešača sa jednim bočnim opsegom na Ku opsegu", magistarski rad, Elektrotehnički fakultet, Univerzitet u Beogradu (1988).

M72 – Докторска дисертација

1. B. Jokanović., "Analiza novih dvostrukih-Y baluna i njihova primena u kolima mikrotalasnih mešača", doktorska disertacija, Elektrotehnički fakultet, Univerzitet u Beogradu (1999).

90 – Патенти

M94 – Објављен патент на националном нивоу

1. М. Нинић, **Б. Јокановић**, *Реконфигурабилни и електронски подесиви филтри са вишеструким сплит-ринг резонаторима*, Регистрован патент П-2016/0031.

II. РУКОВОЂЕЊЕ И УЧЕШЋЕ НА ПРОЈЕКТИМА

Б. Јокановић је руководила следећим пројектима:

1. "Planarna slot antena na 10.5 GHz za radar koji odredjuje brzinu topovskog zrna", za fabriku "Rudi Čajevec" iz Banja Luke u periodu 1979.-1980.
2. "Ultraširokopojasni blokovi i komponenate za radarske ometače MIK-3"– istraživački projekat za potrebe JNA u periodu 1987.–1990. godine.
3. "Radio-relejni uredjaj za digitalni prenos signala u opsegu 21-24 GHz za brzine prenosa 2 i 8 Mbit/s (RRU 23/2/8) "za JP PTT saobraćaja "Srbija" u periodu 1991-1995. Uređaj je uspešno realizovan i u novembru 1995. godine dobio atest ZJ PTT. Više ovakvih uređaja se nalazi u eksploataciji u javnoj i pejdžing mreži JP PTT saobraćaja "Srbija".
4. "Mikrotalasni sistemi za prenos digitalnih signala", Strateški projekat S. 327, Republičkog ministarstva za nauku i tehnologiju u periodu 1994.-1996. godine. B. Jokanović je rukovodilac potprojekta.
5. "Fiksna bežična Internet mreža", (IT.1.15.0229.B) za Ministrastvo za nauku i tehnološki razvoj u periodu od 2002.-2004. godine. Projekat je iz Programa tehnološkog razvoja.
6. "Nova generacija milimetarskih linkova na bazi nanostrukturisanih materijala", (PTR 2002.B)- Inovacioni projekat iz Programa tehnološkog razvoja za Ministrastvo za nauku i tehnološki razvoj u periodu od 2004.-2007.
7. "Antikolizioni radarski sistem na 24 GHz", (TP-6110.B) za Ministarstvo nauke i zaštite životne sredine u periodu 2004.-2006. godine. Projekat je iz Programa tehnološkog razvoja.
8. "Metamaterijali za širokopojasne bežične komunikacije i RF identifikaciju", (E! 3853-METATEC), Eureka projekt Universitat Autonoma de Barcelona, Spain, 2006.-2008. Б. Јокановић је руководила делом пројекта у Институту ИМТЕЛ.
9. "20GHz GaN Wide-band Receiver", University of Hawaii, University of Florida, Northrop Grumman, 2006.- jul 2008. Б. Јокановић је била сарадник на пројекту.
10. "Large Area Fabrication of 3D Negative Index Materials by Nanoimprint Lithography", (NIM_NIL), FP project NMP-2008-2.2-2 —Nanostructured meta-materials (2010-2013). Б. Јокановић је сарадник на пројекту.
11. "Дуал-банд и три-банд микроталасна кола и антене на бази метаматеријала за комуникационе системе нове генерације", ТР 11009 (2009-2011).

12. “Реконфигурабилне мултибанд и скениране антене на бази метаматеријала за бежичне комуникације и сензоре”, ТР 32024 (2011-2019).
13. “Генерисање и карактеризација нанофотонских функционалних структура у биомедицини и информатици”, III45015, руководилац подпројекта “Фотонску метаматеријали”, (2011-2019).
14. “Reconfigurable and Multiband Devices and Antennas Based on Innovative Metamaterial Concepts”, билатерални пројекат са Шпанијом, (2011-2012).
15. “Advanced Multi-Beam and Scanning Antennas for 5G and Radar Applications”, билатерални пројекат са Немачком (2018-2019).

III. ОСТАЛИ ПОКАЗАТЕЉИ УСПЕХА

3.1. Награде

1. Награда Института ИМТЕЛ за научни допринос 1996. године,
2. IEEE Third Millennium Medal 2000. године,
3. Награда Југословенског удружења за микроталасну технику и технологију-YU MTT 2005. године,
4. Награда Проф. Александар Маринчић за најбољи рад публикован 2013,
5. Награда Проф. Илија Стојановић за најбољи рад објављен 2015. године,
6. Неколико награда за најбоље радове на Антенској и Микроталасној секцији ЕТРАН-а.

Република Србија
МИНИСТАРСТВО НАУКЕ
Комисија за стицање научних звања

Број:06-00-69/490
16.04.2008. године
Б е о г р а д

На основу члана 22. става 2. члана 70. став 7. Закона о научноистраживачкој делатности ("Службени гласник Републике Србије", број 110/05 и 50/06 - исправка), члана 34. и 36 став 1. Правилника о поступку и начину вредновања и квантитативном исказивању научноистраживачких резултата истраживача ("Службени гласник Републике Србије", број 35/07) и захтева који је поднео

Електротехнички факултет у Београду

Комисија за стицање научних звања на седници одржаној 16.04.2008. године, донела је

ОДЛУКУ
О СТИЦАЊУ НАУЧНОГ ЗВАЊА

Др Бранка Јокановић

стиче научно звање

Научни саветник

у области техничко-технолошких наука - електроника и телекомуникације

О Б Р А З Л О Ж Е Њ Е

Електротехнички факултет у Београду

утврдио је предлог број 2570/4 од 22.01.2008. године на седници наставно-научног већа Факултета и поднео захтев Комисији за стицање научних звања број 189 од 29.01.2008. године за доношење одлуке о испуњености услова за стицање научног звања ***Научни саветник.***

Комисија за стицање научних звања је по предходно прибављеном позитивном мишљењу Матичног научног одбора за електронику и телекомуникације на седници одржаној 16.04.2008. године разматрала захтев и утврдила да именована испуњава услове из члана 70. став 7. Закона о научноистраживачкој делатности ("Службени гласник Републике Србије", број 110/05 и 50/06 - исправка), и члана 34. и 36 став 1. Правилника о поступку и начину вредновања и квантитативном исказивању научноистраживачких резултата истраживача ("Службени гласник Републике Србије", број 35/07) за стицање научног звања ***Научни саветник,*** па је одлучила као у изреци ове одлуке.

Доношењем ове одлуке именована стиче сва права која јој на основу ње по закону припадају.

Одлуку доставити подносиоцу захтева, именованој и архиви Министарства науке у Београду.

ПРЕДСЕДНИК КОМИСИЈЕ
Др Станислава Стошић-Грујичић,
научни саветник

МИНИСТАР
Др Ана Пешикан

РЕПУБЛИКА СРБИЈА МИНИСТАРСТВО НАУКЕ БЕОГРАД

BIOGRAFIJA: Prof. dr ANA JOVANOVIĆ

Prof. dr Ana Jovanović rođena je u Nikšiću 03.02.1970. godine, gdje je završila osnovnu i srednju školu sa odličnim uspjehom (usmjerenje: "Pomoćni istraživač u matematici"). Za postignute rezultate u učenju nagrađena je diplomom Luča I.

Školske 1988/89. godine upisala je studije Elektrotehnike- smjer Elektronika, na Elektrotehničkom fakultetu u Podgorici. Na istom fakultetu je diplomirala 14.07.1994. godine odbranivši diplomski rad pod nazivom „Grinova funkcija u elektrostatici" sa ocjenom 10 (deset).

Poslijediplomske studije upisala je školske 1995/96. godine na Elektrotehničkom fakultetu u Podgorici, smjer Teorijska elektromagnetika. Magistarski rad pod nazivom „Određivanje karakteristika emisionih antena modifikovanim metodom najmanjih kvadrata" odbranila je 23.09.1998. godine.

Doktorsku disertaciju pod nazivom „Analiza složenih antenskih struktura metodom najmanjih kvadrata" odbranila je 21.06.2004. godine na Elektotehničkom fakultetu, Univerziteta Crne Gore u Podgorici.

Naučno-istraživački rad Prof. dr Ane Jovanović se odvija u oblasti Teorijske elektromagnetike, preciznije, u najvećoj mjeri vezan je za analizu i optimizaciju složenih antenskih sistema Njen dosadašnji naučno-istraživački rad rezultovao je objavljivanjem velikog broja naučnih radova u međunarodnim i domaćim časopisima, kao i na međunarodnim i domaćim naučnim skupovima. Učestvovala je u realizaciji više naučno-istraživačkih projekata kao aktivni istraživač.

U zvanje saradnika na Katedri za teorijsku elektrotehniku, Elektrotehničkog fakulteta, Univerziteta Crne Gore u Podgorici, izabrana je 01.12.1994. godine. Odlukom Naučno-nastavnog vijeća Elektrotehničkog fakulteta, od 13. juna 2001. godine, izabrana je u zvanje asistenta na Katedri za teorijsku elektrotehniku.

U zvanje docenta izabrana je 18.04. 2007. godine. Od izbora u nastavničko zvanje izvodi nastavu iz predmeta sa akademskih studijskih programa: Elektromagnetika, Prostiranje i zračenje EMT i Mikrotalasne antene. U zvanje vanrednog profesora na Univerzitetu Crne Gore izabrana je 28.06. 2012. godine. U zvanje redovnog profesora izabrana je 16. oktobra 2017.

Član je tima Laboratorije za mjerenje nivoa elektromagnetnih emisija na Elektrotehničkom fakultetu. Učestvovala je u mjerenjima i izradi velikog broja Izvještaja o ispitivanju nivoa električnog polja.

Član je međunarodnog udruženja inženjera elektrotehnike (IEEE), sekcija za Antene i prostiranja.

Član je Programskog odbora naučno-stručnog skupa Informacione tehnologije.

BIBLIOGRAFIJA Prof. dr Ane Jovanović

Doktorska disertacija:

Ana Jovanović, " Analiza složenih antenskih struktura metodom najmanjih kvadrata " Univerzitet Crne Gore, 24.06.2004.

Magistarska teza:

Ana Jovanović, " Određivanje karakteristika emisionih antena modifikovanim metodom najmanjih kvadrata " Univerzitet Crne Gore, 23.09.1998.

Vodeći međunarodni časopisi:

1. Lazović, L.; Jokanovic, B.; Rubežić, V.; Radovanovic, M.; Jovanović, A. Fractal Cardioid Slot Antenna for Super Wideband Applications. *Electronics* **2022**, *11*, 1043. https://doi.org/10.3390/electronics11071043

2. Rubežić, V., Lazović, L. and Jovanović, A. (2018), "Parameter identification of Jiles–Atherton model using the chaotic optimization method", COMPEL - The international journal for computation and mathematics in electrical and electronic engineering, Vol. 37 No. 6, pp. 2067-2080. https://doi.org/10.1108/COMPEL-11-2017-0496

3. A. Jovanović, L. Lazović and V. Rubežić (2016): "Radiation pattern synthesis using a Chaotic beamforming algorithm", COMPEL-The international journal for computation and mathematics in electrical and electronic engineering, 2016, Vol. 35, Issue 5: 1814-1829, ISSN 0332-1649. https://doi.org/10.1108/COMPEL-08-2015-0299

4. A. Jovanović, L. Lazović and V. Rubežić (2016): "Adaptive array beamforming using a Chaotic beamforming algorithm", International Journal of Antennas and Propagation, 2016, Vol. 2016(2016), ID 8354204, ISSN 1687-5869, E ISSN 1687-5877. https://doi.org/10.1155/2016/8354204

5. A. Jovanović, S. Jovićević, "Field Analysis of the Archimedean Spiral Antenna", Electromagnetics, Vol. 31, No.2, 2011, pp. 147-158, Taylor&Francis. https://doi.org/10.1080/02726343.2011.548198

6. A. Jovanović, S. Jovićević, "A general solution of the Thin Circular Loop Radiatuon" Electromagnetics, Vol. 23, ETRMDV 23(1) 2003, pp. 77-88, Taylor&Francis. https://doi.org/10.1080/02726340390159441

7. S. Jovićević, A. Jovanović, "The Analysis of the Biconical Antenna by the Least-Squares Boundary Residual Method", Int.J.Electron.Commun.(AEU) 57 (2003) No.6, pp. 415-419. https://doi.org/10.1078/1434-8411-54100194

Ostali međunarodni časopisi:

1. Vesna Rubežić, Ana Jovanović," Erbium – Doped Fiber Laser Systems: Routes to Chaos" Serbian Journal of Electrical Engineering, Vol. 11, Issue 4, pp 551-563, 2014.

2. Vesna Rubežić, Milovan Radulović, Ana Jovanović, Miloš Daković, "The chaotic mobile robot", WSEAS TRANSACTIONS on COMPUTERS, Issue 4, Volume 3, pp. 959-962, October 2004, ISSN 1109-2750.

3. V. Rubežić, L. Lazović, M. Babić and A. Jovanović (2016): " Chaotic dynamics in helicopters vibrations", ETF Journal of Electrical Engineering, 2016, Vol 22(1): 34-42, ISSN 0354-8653.

4. L. Lazović, Ž. Zečević, V. Rubežić and A. Jovanović (2016): " A new algorithm for adaptive beamforming", ETF Journal of Electrical Engineering, 2016, Vol 22(1): 5-14, ISSN 0354-8653.

5. A. Jovanović, L. Lazović, V. Rubežić and (2015): "Chaos theory implementation on the LMS algorithm optimization applied on linear antenna arrays", ETF Journal of Electrical Engineering, 2015, Vol 21(1): 128-137, ISSN 0354-8653.

6. A. Jovanović, L. Lazović, V. Rubežić and (2014): "Performance analysis of Capon and Capon-like algorithm for smart antenna system", ETF Journal of Electrical Engineering, 2014, Vol 20(1): 84-93, ISSN 0354-8653.

Konferencije:

1. Mirjana Janjušević, Luka Lazović, Ana Jovanović, Vesna Rubežić, (2021): „Analysis of Ionospheric Effects on the Propagation of Chaotic Signals", , Information Technology (IT) 2021 25th International Conference on, pp. 1-4, 2021.

2. Radovan Čvorović, Luka Lazović, Vesna Rubežić, Ana Jovanović, (2020): "Printed asymmetrical Sierpinski slot antenna for energy harvesting application", Information Technology (IT) 2020 24th International Conference on, pp. 1-4, 2020.

3. L. Lazovic, B. Jokanovic, V. Rubezc and A. Jovanovic, (2020): "Uniplanar Ultra-Wideband Cardioid Slot Antenna for Energy Harvesting Application", 2019 27th Telecommunications Forum (TELFOR), pp. 1-4, 2019.

4. Luka Lazović, Branka Jokanovic, Vesna Rubežić and Ana Jovanović (2019): "Printed Ultra-Wideband Cardioid Monopole Antenna for Energy Harvesting Application", TELSIKS 2019, Sebia, Niš, October 23-25, 2019.

5. L. Lazović, A. Jovanović i V. Rubežić (2018): „ Optimization of fractal antennas in CST with Chaotic optimization algorithm" Zbornik XXIII Naučno-stručnog skupa Informacione tehnologije IT 2018, Žabljak.

6. L. Lazović, A. Jovanović i V. Rubežić (2017): „ Predlog dizajna antene za WiFi podvodne komunikacije" 25nd Telecommunications forum TELFOR 2017, Serbia, Belgrade, November 21-22, 2017.

7. A. Jovanović, V. Vujičić, L. Lazović i V. Rubežić (2018):" Predlog analitičkog modela koji aproksimira prvobitnu krivu magnećenja feromagnetnih materijala", Zbornik 61. konferencije ETRAN, Palić, Jun 2018.

8. L. Lazović, V. Rubežić i A. Jovanović, (2017):„CPW napajana mikrotrakasta monopol antena zasnovana na modifikovanom Sierpinski fraktalu" Zbornik XXII Naučno-stručnog skupa Informacione tehnologije IT 2017, Žabljak, mart 2017., str. 137-140, ISBN: 978-86-85775-20-8.

9. L. Lazović, A. Jovanović, B. Lutovac i V. Rubežić (2016): „Primjena teorije grafova za dizajniranje rekonfigurabilnih fraktalnih antena", 24nd Telecommunications forum TELFOR 2016, Belgrade, Serbia, November 25-27. 2016., ISBN: 978-1-5090-4086-5.

10. L. Lazović, Ž. Zečević, V. Rubežić i A. Jovanović (2016): „Predlog adaptivnog algoritma za redukciju bočnih latica na dijagramu zračenja kod linearnih antenskih nizova", Zbornik 60. konferencije ETRAN, Zlatibor, 13-16 juna 2016., str. AP1.1.1-5, ISBN: 978-86-7466-618-0.

11. A. Jovanović, L. Lazović, V. Rubežić (2015): „Prilagođenje dijagrama zračenja kratkih antenskih nizova upotrebom Haotičnog beamforming algoritma", 23rd Telecommunications forum TELFOR 2015, Belgrade, Serbia, November 24-26. 2015., str. 547-550, ISBN: 978-1-5090-0055-5.

12. L. Lazović, A. Jovanović, V. Rubežić (2015):„Chaos Based Optimization of LMS Algorithm Applied on Circular Antenna Arrays", 4th Mediterranean Conference on Embedded Computing MECO 2015, Budva, jun 2015., pp. 439-442, ISBN: 9781479919772.

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O D L U K U
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Dr Ana Jovanović bira se u akademsko zvanje **redovna profesorica za oblast Teorijska elektrotehnika (Elektromagnetika) na Elektrotehničkom fakultetu**, na neodređeno vrijeme.

Senat Univerziteta Crne Gore
Predsjedavajući

UNIVERZITET CRNE GORE UCG 1974

Prof.dr Danilo Nikolić,v.f.rektora

Crna Gora
UNIVERZITET CRNE GORE
ELEKTROTEHNIČKI FAKULTET

Primljeno	18.10.2017		
Org. jed.	Broj	Prilog	Vrijednost
02/1	2025		

BIOGRAFIJA: Prof. dr VESNA RUBEŽIĆ

Prof. dr Vesna Rubežić je rođena u Podgorici 22.01.1971. godine, gdje je završila osnovnu i srednju školu sa odličnim uspjehom (usmjerenje: "Pomoćni istraživač u matematici"). Za postignute rezultate u učenju nagrađena je diplomom Luča.

Studije na Elektrotehničkom fakultetu u Podgorici - smjer elektronika završila je 1994. godine sa prosječnom ocjenom 9.21 odbranom diplomskog rada pod nazivom „Supstancije u magnetnom polju". Za vrijeme redovnih studija bila je korisnik stipendije Vlade Republike Crne Gore za talentovane studente.

Poslijediplomske studije upisala je školske 1995/96. godine na Elektrotehničkom fakultetu u Podgorici, smjer Teorija električnih kola. Magistarski rad pod nazivom „Haotični fenomeni u električnim kolima" odbranila je 24.09.1998. godine.

Doktorsku disertaciju pod nazivom „Vremensko-frekvencijske reprezentacije u detekciji haotičnih stanja u oscilatornim kolima" odbranila je 29.09.2006. godine na Elektotehničkom fakultetu, Univerziteta Crne Gore u Podgorici.

U zvanje saradnika na Katedri za teorijsku elektrotehniku, Elektrotehničkog fakulteta, Univerziteta Crne Gore u Podgorici, izabrana je 01.12.1994. godine. Odlukom Naučno-nastavnog vijeća Elektrotehničkog fakulteta, od 13. juna 2001. godine, izabrana je u zvanje asistenta na Katedri za teorijsku elektrotehniku.

U zvanje docenta izabrana je 12.06. 2008. godine. Od izbora u nastavničko zvanje izvodi nastavu iz predmeta sa akademskih studijskih programa: Osnovi elektrotehnike II, Nelinearna kola i Mikrotalasna tehnika na Elektrotehničkom fakultetu i Elektrotehnika i elektronika i Osnovi elektrotehnike na Mašinskom fakultetu. U zvanje vanrednog profesora na Univerzitetu Crne Gore izabrana je 26.09. 2013. godine. U zvanje redovnog profesora izabrana je februara 2019.

Dosadašnji naučno-istraživački rad Vesne Rubežić rezultovao je objavljivanjem radova u međunarodnim i domaćim časopisima, kao i na međunarodnim i domaćim naučnim skupovima. Učestvovala je realizaciji više naučno-istraživačkih projekata kao aktivni istraživač.

Član je međunarodnog udruženja inženjera elektrotehnike (IEEE), sekcije za Električna kola i sisteme.

Od septembra 2016. godine obavljala je funkciju rukovodioca studijskog programa Elektronika, telekomunikacije i računari na Elektrotehničkom fakultetu, a od septembra 2019. godine je prodekan za nastavu na Elektrotehnickom fakultetu.

Član je Programskog odbora naučno-stručnog skupa Informacione tehnologije.

Recenzent je u renomiranim međunarodnim časopisima: IEEE Transactions on Circuits and Systems II: Express Briefs, IEEE Access, Signal Processing, Optica Applicata.

BIBLIOGRAFIJA Prof. dr Vesne Rubežić

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Vesna Rubežić, „Vremensko-frekvencijske reprezentacije u detekciji haotičnih stanja u oscilatornim kolima“, Univerzitet Crne Gore, 29.09.2006. godine.

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