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Design and Analysis of an Isosceles-Triangle Antenna for Terrestrial Broadcasting and Satellite Communications Using the Method of Moments

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Abstract

This research presents the design and electromagnetic analysis of an isosceles triangular loop antenna for terrestrial broadcasting and satellite communication applications using the Method of Moments (MoM). The antenna geometry was modeled and analyzed in MATLAB to evaluate its electrical and radiation performance characteristics. The study focused on determining important antenna parameters such as current distribution, radiation resistance, loss resistance, gain, directivity, radiation efficiency, radiated power, and radiation patterns. The designed antenna operated at a resonant frequency of 9.328 MHz with a wavelength of 32.16 cm. Numerical results obtained showed a side length and base length of 8.04 cm, perimeter of 26.08 cm, and radiation resistance of 323.2 Ω. The loss resistance was found to be significantly low at 36.24 Ω, resulting in a high radiation efficiency of 86.5%. The antenna achieved a gain of 1.8758 dBi and a directivity of 0.9375, confirming its directional radiation characteristics. Graphical results from the MoM revealed stable current and phase current distributions along the triangular structure. The radiation pattern plots further demonstrated focused directional radiation with improved electromagnetic energy propagation. The three-dimensional and two-dimensional radiation patterns confirmed the suitability of the antenna for long-distance communication systems. The results obtained indicate that the proposed isosceles triangular loop antenna possesses compact geometry, high efficiency, low power loss, and good directional properties, making it suitable for terrestrial broadcasting and satellite communication applications.

Subject Areas

Cooperative Communications

Keywords

Isosceles Triangular Antenna, Method of Moments, Radiation Pattern, Current Distribution, Radiation Resistance, Satellite Communication, Terrestrial Broadcasting

1. Introduction

Recently, the advancement of wireless communication systems has increased the demand for compact, efficient, and highly directional antennas for terrestrial broadcasting and satellite communication applications. Modern communication systems require antennas with stable radiation characteristics, high efficiency, and low power losses. Consequently, several antenna geometries have been designed to improve electromagnetic performance while reducing antenna size and structural complexity. Among these geometries, triangular antennas have gained attention because of their compact structure, simple configuration, and favorable radiation properties [1]. Loop antennas are widely used in communication engineering due to their simplicity, ease of fabrication, and effective radiation characteristics. Isosceles triangular loop antennas provide improved directional properties and compactness compared to conventional circular and rectangular loop antennas. Isosceles triangular loop geometrical symmetry supports balanced current distribution, stable phase response, and enhanced radiation efficiency, making it suitable for satellite communications, radar systems, microwave systems, and wireless communication applications [2].

The growth of satellite communication systems and next-generation wireless networks has further increased the need for highly directional antennas capable of supporting reliable long-distance communication. Satellite communication systems require antennas with stable radiation patterns, efficient power transfer, and improved signal propagation characteristics [3]. The Method of Moments (MoM) is one of the most effective numerical techniques used in antenna analysis and electromagnetic field computation [4] [5], and [6]. It is widely applied in solving integral equations associated with wire and planar antennas because of its high computational accuracy and efficiency. The Method of Moments transforms electromagnetic boundary equations into matrix equations that can be solved numerically to determine current distribution, input impedance, radiation resistance, and radiation patterns [4] and [5].

Several studies have investigated triangular antenna geometries using analytical and numerical approaches. [7] analyzed a right-angled isosceles triangular patch antenna and reported good impedance matching and radiation performance for microwave communication systems. [8] developed a circularly polarized equilateral triangular patch antenna for mobile satellite communications and demonstrated stable radiation characteristics and improved gain performance. [9] investigated the input impedance of a microstrip right-angled isosceles triangular patch antenna and showed that triangular geometries provide effective impedance characteristics and resonance stability. [10] also analyzed an equilateral triangular waveguide antenna and confirmed that triangular structures possess desirable radiation behaviour for microwave applications. [11] designed a microstrip line-coupled isosceles triangular loop resonator antenna operating at 5.8 GHz and demonstrated compact geometry with stable radiation performance. Also, [7] proposed an equilateral triangular slot antenna for communication systems and microsatellite applications, reporting improved bandwidth, gain, and directional radiation characteristics.

Despite these contributions, limited studies have focused on wire-based isosceles triangular loop antennas analyzed using the Method of Moments for terrestrial broadcasting and satellite communication applications. Most previous works concentrated mainly on microstrip patch and planar triangular antennas. Therefore, this research focuses on the design and analysis of an isosceles triangular loop antenna using the Method of Moments to evaluate its current distribution, radiation resistance, gain, directivity, efficiency, and radiation patterns using MATLAB simulations for terrestrial broadcasting and satellite communication applications.

2. Methodology

The method adopted in this research is to first determine both the design, operational, and performance parameters of the Isosceles triangle antenna using the following formulas, according [5] [10], and [12] as.

Figure 1 illustrates the geometrical structure of the isosceles triangular antenna designed in this study. The figure shows the triangular configuration consisting of two equal side lengths joined to a base conductor, forming an isosceles triangular loop. The geometry demonstrates structural symmetry, which is important for achieving balanced current distribution and stable radiation patterns. The equal side lengths ensure that electromagnetic currents flow uniformly along both sides of the antenna, thereby reducing phase imbalance and improving radiation efficiency.

The triangular configuration also provides a compact antenna structure compared to conventional rectangular or circular loop antennas. This compactness makes the antenna suitable for portable and space-constrained communication systems. The apex angle of the triangle significantly influences the resonant frequency, impedance characteristics, and radiation pattern of the antenna. By properly selecting the geometrical dimensions, the antenna achieves effective resonance and directional radiation characteristics.

Figure 1 further demonstrates the simplicity of the antenna structure, which reduces fabrication complexity and construction cost. The geometrical arrangement also supports the formation of standing current waves along the conductor path, thereby enhancing radiation performance. The overall configuration confirms that the antenna structure was carefully designed to optimize current flow, radiation resistance, and electromagnetic field distribution.

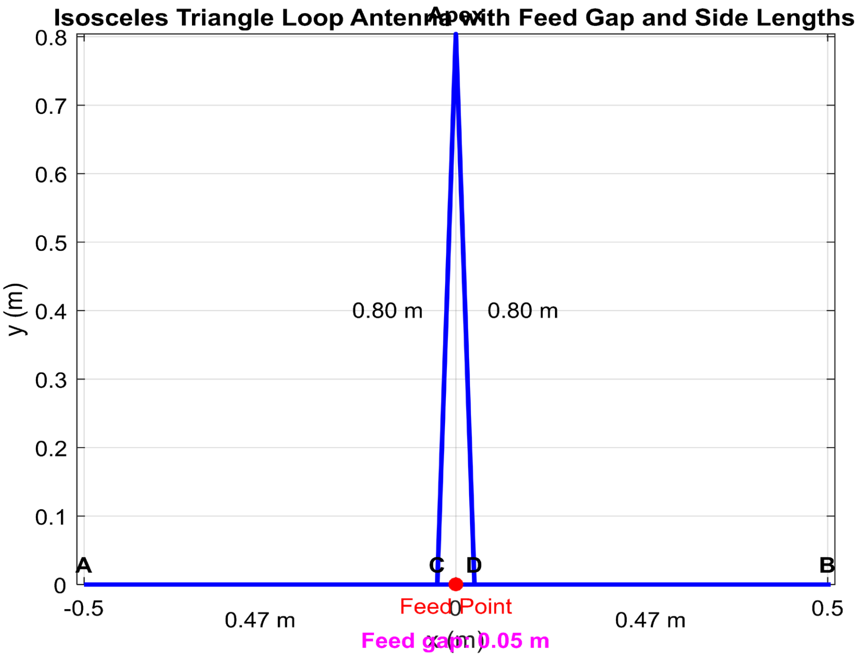

Figure 1. Geometrical configuration of the proposed isosceles triangular loop antenna.

Figure 2 presents a more detailed geometrical representation of the isosceles triangular antenna, showing the side lengths, base conductor, and feed point location. The feed point is positioned at the midpoint of the base conductor CD, which ensures symmetrical excitation of the antenna structure. This central feeding arrangement enables equal current propagation along both equal sides of the triangle, thereby improving current balance and minimizing impedance mismatch. The equal side lengths shown in the figure contribute to uniform phase distribution and stable radiation behavior. Because the feed point is centrally located, the antenna achieves improved radiation symmetry and enhanced directional performance. The diagram also illustrates the relationship between the antenna dimensions and the current path length. Since the perimeter of the triangle determines the effective electrical length of the antenna, the geometrical dimensions directly influence the resonant frequency and radiation resistance.

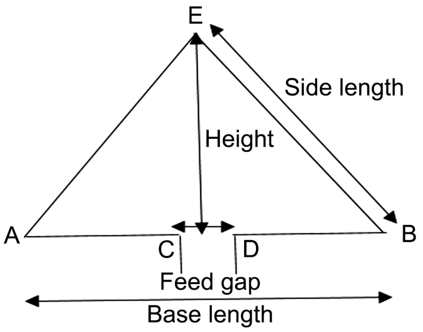

Figure 2. Detailed geometrical and feed point configuration of the proposed isosceles triangular loop antenna.

The feed gap shown in the figure is important because it serves as the excitation region where electrical energy is supplied to the antenna. Proper feed gap spacing ensures efficient power transfer from the transmission line to the radiating structure. Figure 2 therefore provides a clearer understanding of how the antenna geometry, feed arrangement, and conductor dimensions collectively contribute to the radiation performance of the isosceles triangular loop antenna. The symmetrical structure and optimized feed configuration are responsible for the high radiation efficiency and directional characteristics obtained in the results.

3. Computational Design of the Isosceles Triangle Antenna

The design parameters of the antenna considered in this research include the following and the their respective values obtained as.

3.1. Sides Length of the Triangle (*S*)

This formula of Equation (1) is deployed to determine the side lengths of the triangle [13].

$$S = \frac{\lambda}{2(1+\sin\alpha)} \tag{1}$$

where, S is the side length, λ is the wavelength, and α is the angle between the two side lengths

$$\text{let} \quad \lambda = 30\ \text{cm}, \alpha = 60^\circ$$

$$S = \frac{30}{2(1+\sin 60^\circ)} = \frac{30}{2(1+0.866)} = \frac{30}{3.733} = 8.04\ \text{cm}$$

3.2. Base Length (*b*)

The base side length of the isosceles triangular antenna is calculated using equation (2), [7] as;

$$b = 2S\sin\left(\frac{\alpha}{2}\right) \tag{2}$$

$$\text{let} \quad S = 8.04\ \text{cm}, \alpha = 60^\circ$$

$$b = 2S\sin\left(\frac{60^\circ}{2}\right) = 2\times 8.04\sin(30^\circ) = 16.08\times\sin(30^\circ) = 8.04\ \text{cm}$$

3.3. Frequency of an Isosceles Triangle Antenna

The frequency of the antenna is obtained using Equation (3), as

$$f = \frac{c}{4S} \tag{3}$$

where, $c = 3\text{e}8$, the speed of light, and $S = 8.04\ \text{cm}$, the side lengths. Then the frequency is calculated as;

$$f = \frac{3\text{e}8}{4\times 8.04} = 9.328\ \text{MHz}$$

3.4. Electrical Wavelength of the Antenna

This formula of Equation (4) is used to obtain the wavelength of the signal, [11] and [13] as;

$$\lambda = \frac{c}{f} \tag{4}$$

where, f and c are the frequency of the antenna and speed of light respectively. The wavelength is obtained as;

$$\lambda = \frac{3\text{e}8}{9.328\text{e}6} = 32.16\ \text{cm}$$

3.5. Height of the Triangle (*h*)

The height of the isosceles triangular antenna is calculated using Equation (5), [12] as;

$$h = S\sin\frac{\alpha}{2} \tag{5}$$

where α and S are the angle between the side lengths and side length respectively.

From Equation (2) $S = 8.04\ \text{cm}, \alpha = 60^\circ$

Therefore, the height of the antenna is obtained as;

$$h = 8.04\sin\frac{60^\circ}{2} = 8.04\sin 30^\circ = 8.04 \times 0.5 = 4.02\ \text{cm}$$

3.6. Perimeter (*p*)

The perimeter side of the isosceles triangular antenna is calculated using; [14]

$$p = 2S + b \tag{6}$$

where, b is the base length and S is the side lengths of the isosceles triangle antenna.

$$S = 8.04\text{, and } b = 10\ \text{cm}$$

$$p = 2S + b = 16.08 + 10 = 26.08\ \text{cm}$$

3.7. Area of an Isosceles Triangle

The area of the isosceles triangular antenna is calculated using, [14];

$$A = \frac{bh}{2} \tag{7}$$

where b is base length and h is height. If the height is unknown, the following formula can be applied

$$A = \frac{b}{4}\sqrt{4a^2 - b^2} \tag{7a}$$

where a the length of equal is sides and b is the base length. From equation (2.7), the area of an Isosceles triangle is calculated as;

$$A=\frac{8.04}{4}\sqrt{4\times 8.04^2-8.04^2}$$
$$=2.02\sqrt{4\times 64.64-64.64}=2.02\sqrt{258.56-64.64}$$
$$=2.02\sqrt{193.92}=2.02\times 13.93=28.14\ \text{cm}^2$$

3.8. Number of Turns (*N*)

The number of turns of the isosceles triangular antenna is calculated using Equation (8), [12] as;

$$N=\frac{p}{\lambda} \tag{8}$$

where, p = perimeter of the triangular loop antenna

let $p=26.08\ \text{cm}$, $\lambda=32.16\ \text{cm}$,

$$N=\frac{26.08}{32.16}=0.81\approx 1\ \text{turns}$$

3.9. Conductor Diameter (*d*)

The conductor diameter of the isosceles triangular antenna is calculated using Equation (9), [13] as;

$$d=\sqrt{\frac{4S^2}{\pi^2\left(p^2-\frac{4S^2}{\pi^2}\right)}} \tag{9}$$

where, $S=8.04\ \text{cm}, p=24.12\ \text{cm}, L=90\ \text{cm}$

$$d=\sqrt{\frac{4\times 8.04^2}{\pi^2\left(26.08^2-\frac{4\times 8.04^2}{\pi^2}\right)}}$$
$$=\sqrt{\frac{258.57}{9.8696\left(680.166-\frac{258.57}{9.8696}\right)}}=\sqrt{\frac{258.57}{9.8696(680.166-40.57)}}$$
$$=\sqrt{\frac{258.57}{9.8696\times 639.9}}=\sqrt{\frac{258.57}{6{,}315.56}}=\sqrt{0.0409}=0.20\ \text{cm}$$

3.10. Gain (*G*)

The gain of the isosceles triangular antenna is calculated using Equation (10), [12] as;

$$G=\frac{30N^2S^2}{\lambda^2} \tag{10}$$

where, $N=1\ \text{turns}, S=8.04\ \text{cm}, \lambda=32.16\ \text{cm}$

$$G=\frac{30\times 1\times 8.04^2}{32.16^2}=\frac{30\times 1\times 64.64}{1034.2656}=\frac{1939.2}{1034.2656}=1.875\ \text{dBi}$$

3.11. Directivity (D)

The directivity of the isosceles triangular antenna is calculated using Equation (11), [13] as;

$$\text{gain, directi} \tag{11}$$

$$\text{let} \quad N = 1\ \text{turns}, S = 8.04\ \text{cm}, \lambda = 32.16\ \text{cm}$$

$$\frac{15\times 1^2 \times 8.04^2}{32.16^2} = \frac{15\times 1\times 64.64}{1034.2656} = \frac{969.6}{1034.2656} = 0.9375$$

3.12. Radiation Efficiency ϵ

The radiation efficiency of the isosceles triangular antenna is calculated using Equation (12), [13] as

$$\epsilon = \frac{R_r}{R_r + R_L}\times 100 \tag{12}$$

where R_L = loss resistance

$$\text{let} \quad R_r = 232.2\ \Omega, R_L = 36.24\ \Omega$$

$$\epsilon = \frac{232.2}{232.2+36.24}\times 100 = \frac{232.2}{268.44}\times 100 = 86.5\%$$

3.13. Radiation Resistance R_r

The radiation resistance of the isosceles triangular antenna is calculated using Equation (13) as;

$$R_r = \frac{3720 N^2 S^2}{\lambda^2} \tag{13}$$

$$R_r = \frac{120\pi^2 N^2 S^2}{\lambda^2}$$

$$\text{let} \quad N = 1\ \text{turns}, S = 8.04\ \text{cm}, \lambda = 32.16\ \text{cm}$$

$$R_r = \frac{37201\times 8.04^2}{32.16^2} = \frac{3720\times 1\times 64.64}{1034.2656} = 232.5\ \Omega$$

3.14. The Loss Resistance R_L

The loss resistance of the isosceles triangular antenna is calculated using Equation (14), [13] as;

$$R_L = \frac{\rho L}{A\left(1-\frac{\lambda^2}{4(\pi S)^2}\right)} \tag{14}$$

where, ρ - is the resistivity of the wire conductor, $= 1.68\times 10^{-8}\ \Omega\cdot\text{m}$, $L = S = 8.04\ \text{cm}$, A is the area of the Isosceles triangle antenna, $A = 28.14\ \text{cm}^2$ and the wavelength is $\lambda = 32.16\ \text{cm}$.

Therefore, the loss resistance is obtained as;

$$R_L = \frac{1.68\times10^{-8}\times8.04}{28.14\left(1-\dfrac{32.16^2}{4(\pi\times8.04)^2}\right)} = \frac{13.5072\times10^{-8}}{28.14\left(1-\dfrac{1034.2656}{4(25.23)^2}\right)}$$

$$= \frac{13.5072\times10^{-8}}{28.14\left(1-\dfrac{1{,}034.2656}{2{,}552.27}\right)} = \frac{13.5072\times10^{-8}}{28.14(1-0.40523)}$$

$$= \frac{13.5072\times10^{-8}}{28.14\times0.59477} = \frac{13.5072\times10^{-8}}{16.7368} = 36.24\,\Omega$$

3.15. Total Radiated Power P_r

The power radiated by the isosceles triangular antenna is calculated using Equation (15), [13] as;

$$P_r = \frac{I^2 R_r}{2} \tag{15}$$

$$\text{let} \quad I = 1\,\text{A}, R_r = 232.2\,\Omega,$$

$$P_r = \frac{232.2}{2} = 116.1\ \text{Watt}$$

3.16. Radius of the Wire Conductor, *r*

The radius of the wire conductor of the isosceles triangular antenna is calculated using Equation (16), [13] as;

$$r = \sqrt{\frac{\left(\dfrac{d}{2\pi N}\right)}{1+\dfrac{d}{4\pi NS}}} \tag{16}$$

where d = diameter of the wire conductor

$$\text{Let} \quad d = 0.6958\ \text{cm}, N = 1\ \text{turns}, S = 8.04\ \text{cm}$$

$$r = \sqrt{\frac{\left(\dfrac{0.20}{2\pi\times1}\right)}{1+\dfrac{0.20}{4\pi\times1\times8.04}}} = \sqrt{\frac{\left(\dfrac{0.20}{6.2832\times1}\right)}{1+\dfrac{0.20}{12.5664\times1\times8.04}}}$$

$$= \sqrt{\frac{\left(\dfrac{0.20}{6.2832}\right)}{1+\dfrac{0.20}{101.03}}} = \sqrt{\frac{0.032}{1+0.006887}} = \sqrt{\frac{0.032}{1.006887}}$$

$$= \sqrt{0.032} = 0.179\ \text{cm}$$

3.17. Feed Point Location *x*

The feed point location of the isosceles triangular antenna is calculated using Equation (17), [13] as;

$$x = \frac{S}{2\pi}\left(1 - \frac{1}{2\sqrt{N}}\right) \tag{17}$$

Let $S = 8.04\ \text{cm}, N = 1\ \text{turns}$,

$$x = \frac{8.04}{2\pi}\left(1 - \frac{1}{2\sqrt{1}}\right) = \frac{8.04}{6.2832} \times \left(1 - \frac{1}{2}\right)$$

$$= 1.2796(1 - 0.5) = 1.2796 \times 0.5 = 0.6398\ \text{cm}$$

4. Discussion of Results

The results are presented in tabular and graphical forms to facilitate comprehensive analysis and discussion.

Table presents the following antenna design and performance parameters. The parameters presented in Table 1 include; the side length S, base length b, frequency f, wavelength λ, height h, perimeter p, area of the triangle A, number of turns N, diameter of wire d, gain G, directivity D, radiation resistance R_r, loss resistance R_L, power radiated P_r, radius of wire r, and feed point location FPL. The values presented in Table 1 were obtained from analytical calculations using antenna geometry illustrated in Figure 1.

Table 1. Values of the antenna parameter.

S/N	Parameter of the Antenna	Value
1	Side length S (cm)	8.04
2	Base length b (cm)	8.04
3	Frequency f (MHz)	9.328
4	Wavelength λ (cm)	32.16
5	Height, h (cm)	4.02
6	Perimeter, p (cm)	26.08
7	Area, A (cm)	28.14
8	Number of turns N	1
9	Diameter of wire, d (cm)	0.20
10	Gain (dBi), G	1.8758
11	Directivity, D	0.9375
12	Radiation Resistance R_r (Ω)	323.2
13	Loss Resistance R_L (Ω)	36.24
14	Radiated Power P_r (watt)	116.1
15	Radius r (cm)	0.179
16	Feed Point Location x (cm)	0.6398
17	Radiation Efficiency, ϵ	86.5%

Table 1 contain the calculated design and performance parameters of the isosceles triangular loop antenna used in this research. These parameters define the physical dimensions, electrical properties, and radiation characteristics of the antenna. The side length and base length of the antenna were both obtained as 8.04 cm, confirming that the antenna geometry approaches an equilateral-like isosceles triangular structure. This balanced geometry contributes to uniform current distribution and symmetrical radiation characteristics. The antenna operates at a resonant frequency of 9.328 MHz with a corresponding wavelength of 32.16 cm. These values indicate that the antenna is designed for high-frequency terrestrial broadcasting and satellite communication applications. The relationship between wavelength and antenna dimensions confirms that the antenna was properly scaled to support resonance at the selected operating frequency.

The height of the triangle was obtained as 4.02 cm, while the perimeter was calculated as 26.08 cm. These geometrical parameters influence the effective current path length and consequently affect the radiation resistance and resonant behaviour of the antenna. The calculated area of 28.14 cm^2 indicates that the antenna occupies a compact physical space while still maintaining adequate radiation capability. This compactness makes the antenna suitable for applications where space limitation is important. The antenna uses a single turn conductor configuration with a wire diameter of 0.20 cm and radius of 0.179 cm. These conductor dimensions contribute to reduced conductor losses and improved current conduction along the antenna structure.

The gain of 1.8758 dBi and directivity value of 0.9375 confirm that the antenna exhibits directional radiation characteristics. These values indicate that the antenna is capable of concentrating radiated power in a preferred direction, which is desirable for long-distance signal transmission. The radiation resistance was obtained as 323.2 Ω, while the loss resistance was only 36.24 Ω. Since the radiation resistance is significantly greater than the loss resistance, the antenna efficiently converts input electrical power into electromagnetic radiation. This directly resulted in a high radiation efficiency of 86.5%. The radiated power of 116.1 W demonstrates that the antenna is capable of transmitting significant electromagnetic energy into free space. The feed point location of 0.6398 cm also confirms that the excitation position was carefully selected to achieve impedance matching and stable current distribution. Overall, the parameters presented in **Table 1** validate the effectiveness of the antenna design and confirm that the isosceles triangular loop antenna possesses good radiation performance, high efficiency, and directional characteristics suitable for communication applications.

Figure 3 illustrates the current distribution along the isosceles triangular loop antenna obtained using the Method of Moments (MoM). The graph shows that the current magnitude is highest near the feed point and gradually decreases along the triangular conductor sections toward the terminal ends. This behavior is expected in resonant loop antennas because the excitation source injects maximum current at the feed region while energy propagation along the conductor results in gradual attenuation.

The smooth variation of current along the antenna confirms proper impedance continuity and efficient electromagnetic coupling throughout the loop structure. The absence of abrupt discontinuities further validates the effectiveness of the MoM in accurately solving the electric field integral equation governing the antenna current distribution. The balanced current flow also indicates stable radiation behavior and efficient energy transfer from the feed line to free space radiation. The current concentration around the lower region of the triangle demonstrates that the antenna geometry effectively supports resonant standing-wave formation. This contributes significantly to the directional radiation characteristics of the antenna.

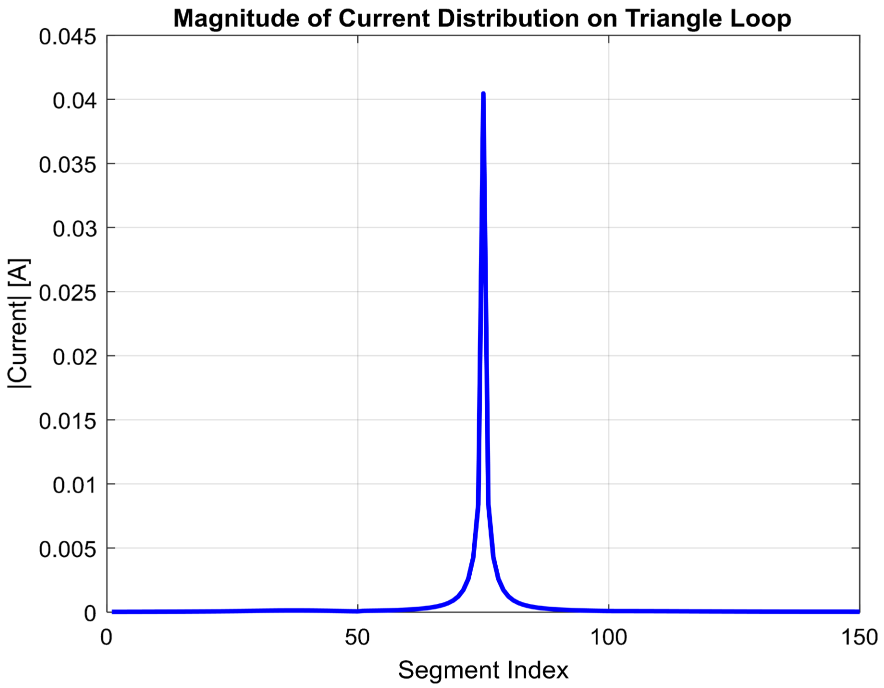

Figure 3. Graph of current distribution on isosceles triangle loop antenna using MoM.

Figure 4 presents the phase current distribution across the triangular antenna structure. The graph indicates a progressive variation in current phase along the conductor length, confirming that the antenna supports traveling and standing wave components simultaneously. The phase variation is important because it determines the constructive and destructive interference of the radiated electromagnetic fields. A smooth phase transition across the antenna elements ensures coherent radiation and enhances directional performance. The nearly symmetrical phase response observed along both equal sides of the triangle confirms the geometrical symmetry of the antenna. This phase behavior contributes directly to the radiation efficiency and directivity obtained from the design. The results also demonstrate that the MoM formulation successfully captures the phase relationship of the induced currents, which is essential in predicting the far-field radiation pattern accurately.

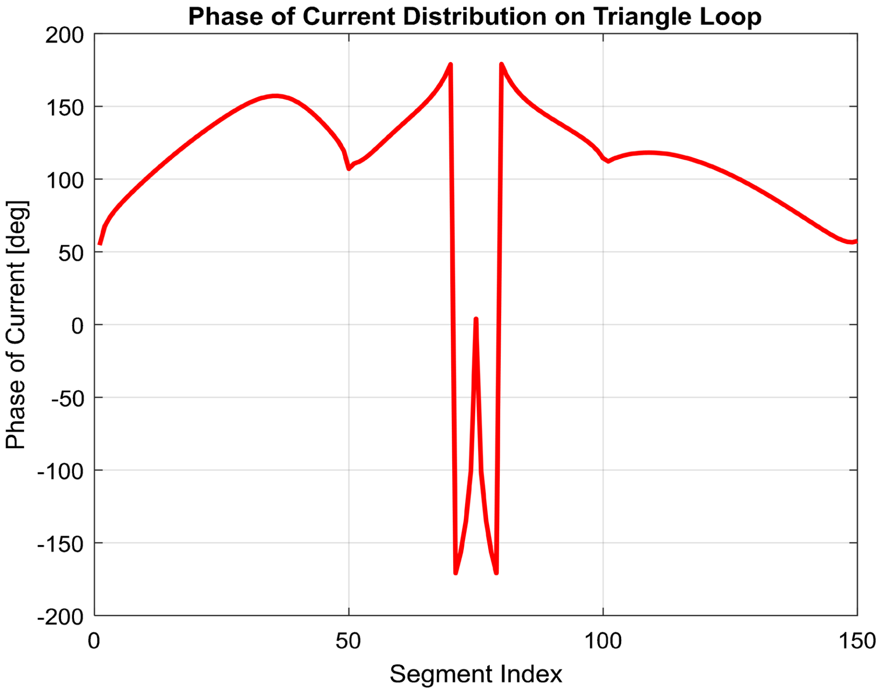

Figure 4. Graph of phase current distribution on isosceles triangle loop antenna using MoM.

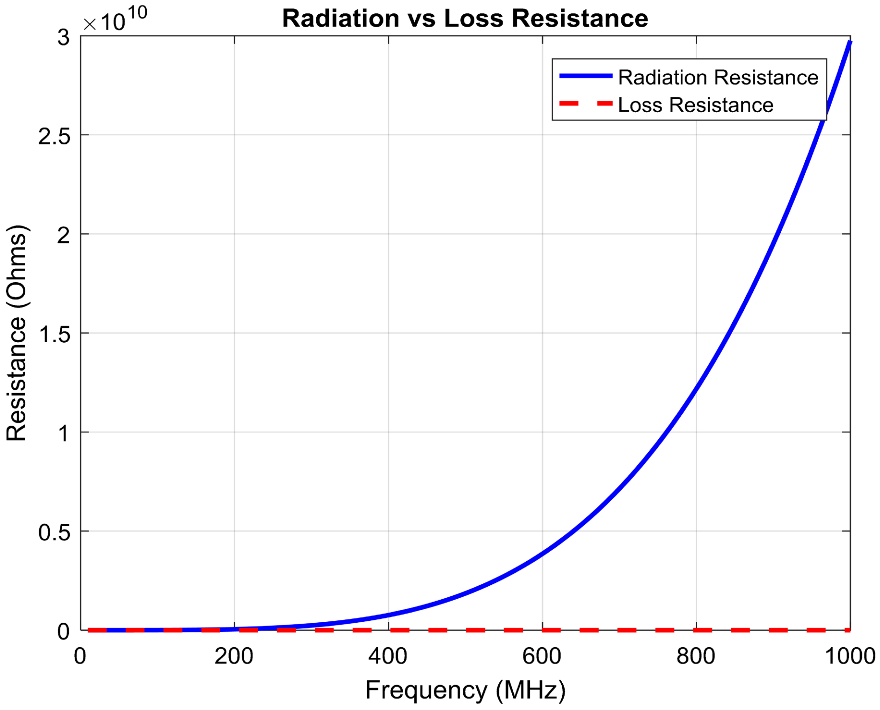

Figure 5. Graph of radiation and loss resistance.

Figure 5 shows graphs of radiation and loss resistances as displayed by the legend. **Figure 3** shows the variation of radiation resistance and loss resistance of the antenna. The radiation resistance curve increases progressively with frequency, indicating improved radiation capability as the operating frequency rises. Radiation resistance represents the portion of antenna resistance responsible for electromagnetic wave radiation into free space. The increase in radiation resistance implies that the antenna becomes more effective in converting input electrical power into radiated electromagnetic energy at higher frequencies. The maximum radiation resistance value obtained was approximately 323.2 Ω, which confirms efficient radiation performance.

The loss resistance curve remains extremely small compared to the radiation resistance. This indicates that only a negligible amount of input power is dissipated as heat within the conductor. The large loss resistance is desirable because it improves overall antenna efficiency. The large difference between radiation resistance and loss resistance validates the high radiation efficiency obtained in the research. This result confirms that the isosceles triangular loop antenna possesses good conductive and radiating properties suitable for terrestrial and satellite communication applications.

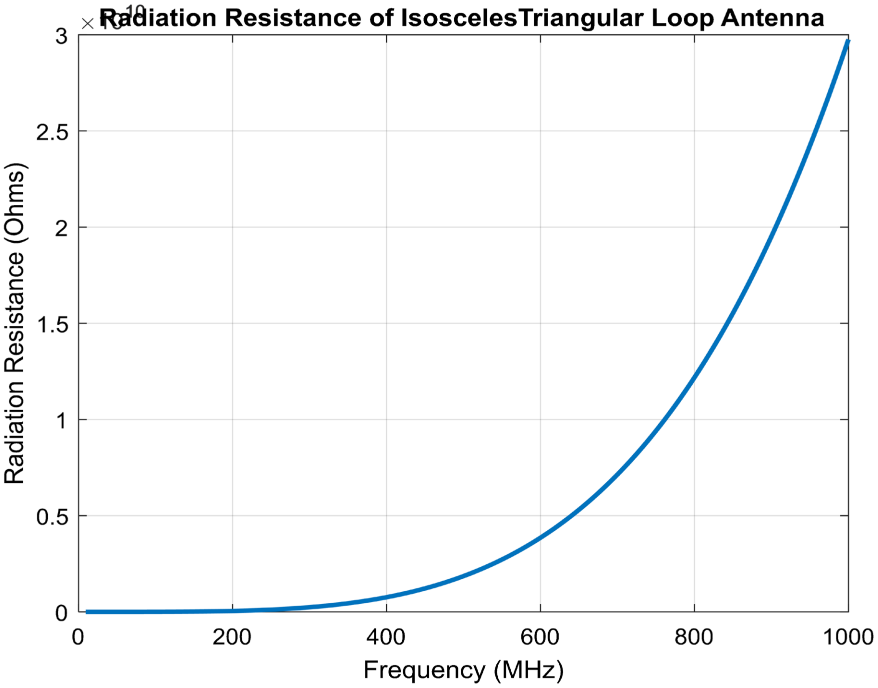

Figure 6. Graph of radiation resistance with frequency.

Figure 6 shows the relationship between radiation resistance and frequency. The graph shows that radiation resistance increases almost linearly with frequency within the analyzed operating range. At lower frequencies, the radiation resistance is relatively small because the electrical length of the antenna is short compared to the wavelength. As frequency increases, the antenna approaches resonant conditions, leading to stronger current radiation and improved electromagnetic coupling with free space. The increase in radiation resistance signifies enhanced radiation capability and improved power transfer efficiency. The graph also demonstrates that the antenna can maintain stable performance over a range of operating frequencies, making it suitable for broadband communication systems. This behavior confirms the theoretical expectation that electrically larger loop structures radiate more efficiently at higher frequencies.

Figure 7 presents the variation of radiation efficiency with frequency. The graph shows that the antenna efficiency increases with operating frequency and eventually approaches a maximum value close to unity. This behavior occurs because radiation resistance becomes dominant over loss resistance at higher frequencies. Since radiation efficiency is defined as the ratio of radiated power to total input power, the reduction in resistive losses leads directly to improved efficiency.

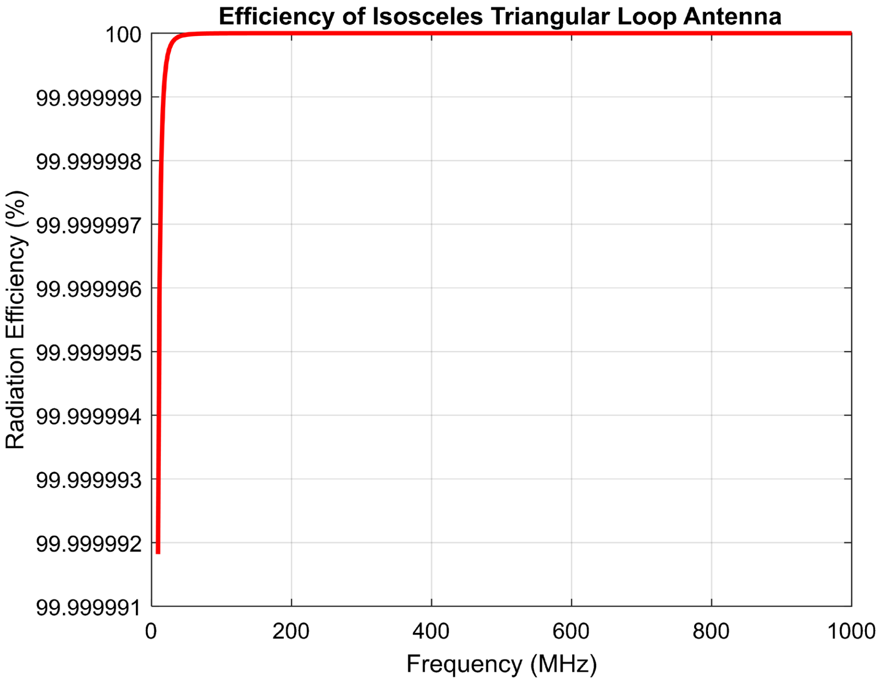

Figure 7. Graph of radiation efficiency with frequency.

The high efficiency obtained indicates that the isosceles triangular loop antenna effectively converts supplied electrical energy into electromagnetic radiation with minimal internal power dissipation. This characteristic is particularly important in satellite communication systems where efficient power utilization is critical. The graph also confirms that the selected antenna geometry and conductor dimensions are appropriate for minimizing conductor losses while maximizing radiation performance.

Figure 8 illustrates the three-dimensional radiation pattern of the isosceles triangular antenna. The pattern exhibits a directional radiation characteristic with a clearly defined major lobe concentrated along a preferred direction. The existence of a dominant main lobe indicates that the antenna efficiently focuses radiated energy toward a specific spatial region rather than radiating uniformly in all directions. This directional property is advantageous in long-distance terrestrial broadcasting and satellite communication systems because it improves signal strength and reduces unnecessary power dispersion.

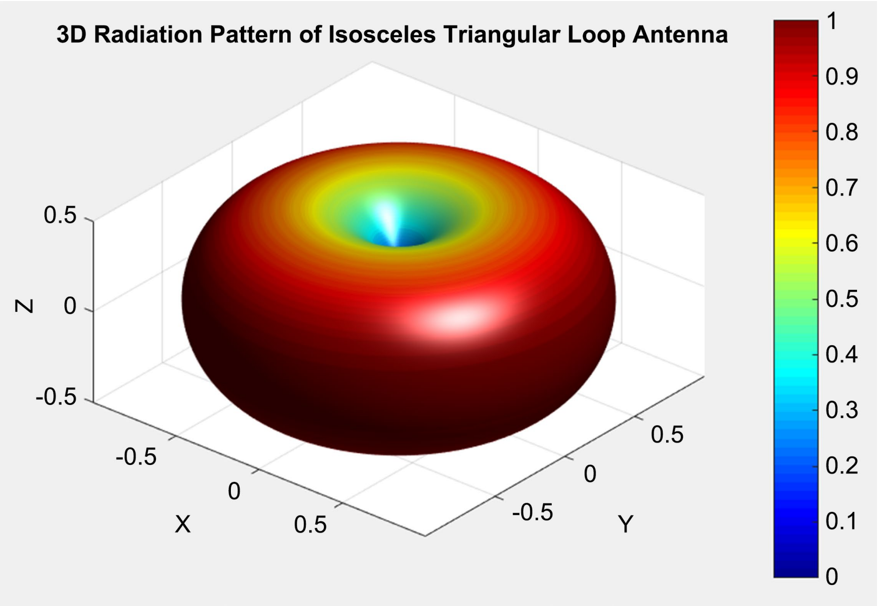

Figure 8. A 3D radiation pattern of isosceles triangular antenna.

The relatively small side lobes observed in the radiation pattern indicate minimal unwanted radiation in undesired directions. This contributes to reduced interference and improved communication reliability. The three-dimensional pattern also confirms the directivity value obtained analytically and demonstrates that the triangular geometry significantly influences the spatial field distribution of the antenna.

Figure 9 presents the two-dimensional polar radiation pattern of the antenna. The graph reveals a directional pattern characterized by a prominent major lobe and reduced radiation intensity in opposite directions. The polar plot demonstrates that the antenna radiates maximum power along specific angular directions. This confirms that the isosceles triangular loop antenna behaves as a directional antenna rather than an omnidirectional radiator. The symmetry observed in the pattern reflects the geometrical symmetry of the antenna structure. The narrow beamwidth shown by the graph suggests improved focusing capability and enhanced gain characteristics. Such directional radiation behavior is desirable in satellite communication systems because it enables efficient signal transmission toward targeted receivers while minimizing interference from surrounding directions.

Figure 10 shows the normalized radiation pattern of the antenna for azimuthal angles of ($\phi = 0^\circ$) and ($\phi = 90^\circ$). The graph illustrates the variation of normalized field intensity with angular displacement. The normalized pattern demonstrates the angular distribution of radiated power independent of absolute magnitude. The presence of dominant lobes confirms strong radiation concentration along preferred directions, while null regions indicate directions where radiation is minimal. The variation between the two angular planes indicates that the antenna radiation characteristics depend on spatial orientation. This confirms the anisotropic radiation nature of the triangular geometry. The normalized radiation response further validates the antenna's directional capability and supports its application in communication systems requiring focused electromagnetic radiation patterns with minimal power loss.

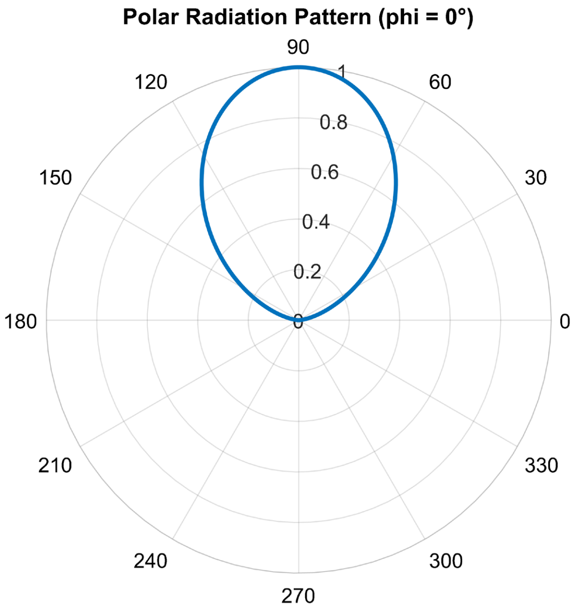

Figure 9. A 2D polar radiation pattern of isosceles triangular antenna.

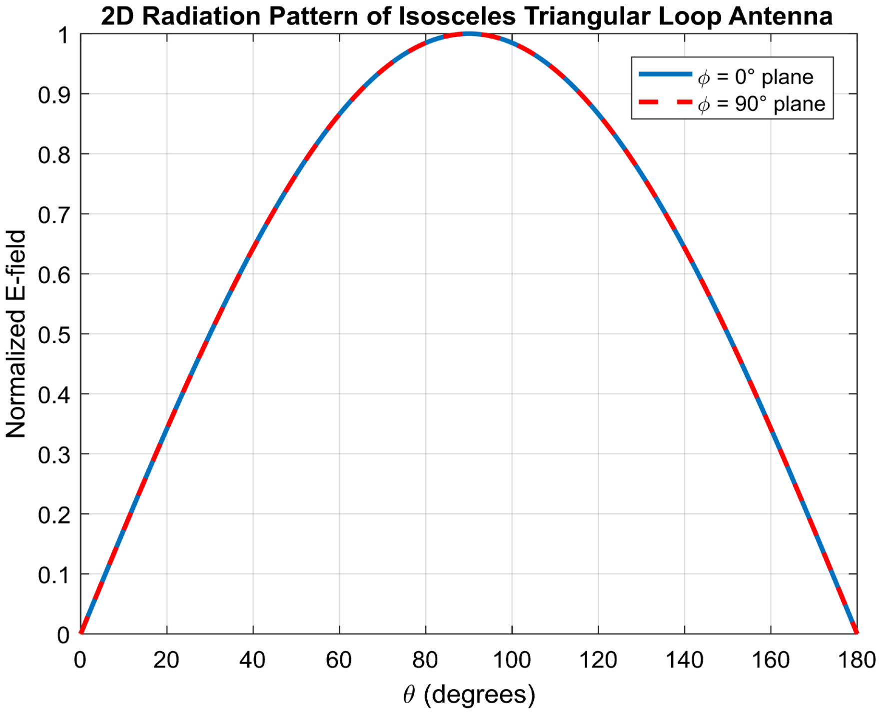

Figure 10. A 2D normalized radiation pattern of isosceles triangular antenna.

5. Findings of the Research

The following findings were obtained from the design and analysis of the isosceles triangular loop antenna using the Method of Moments (MoM):

1) The designed isosceles triangular loop antenna successfully resonated at an operating frequency of 9.328 MHz with a corresponding wavelength of 32.16 cm, confirming the validity of the adopted design equations and geometrical configuration.

2) The antenna geometry produced stable current and phase current distributions along the triangular conductor structure, demonstrating that the Method of Moments is effective for analyzing current behavior in wire-loop antennas.

3) The radiation resistance of the antenna was obtained as 323.2 Ω, which indicates efficient conversion of input electrical power into radiated electromagnetic energy.

4) The loss resistance was significantly lower than the radiation resistance, with a value of 36.24 Ω, confirming minimal conductor losses and reduced power dissipation within the antenna structure.

5) The antenna achieved a high radiation efficiency of 86.5%, indicating that most of the supplied power was effectively radiated into free space.

6) The gain of the antenna was obtained as 1.8758 dBi, while the directivity was 0.9375, confirming that the antenna possesses directional radiation characteristics suitable for long-distance communication systems.

7) The total radiated power of the antenna was found to be 116.1 W, demonstrating the capability of the antenna to transmit substantial electromagnetic energy effectively.

8) The graphical results revealed that radiation resistance increases with frequency, implying improved radiation capability as the operating frequency rises.

9) The radiation efficiency graph showed that the antenna efficiency improves with frequency due to the dominance of radiation resistance over loss resistance.

10) The three-dimensional and two-dimensional radiation patterns confirmed that the antenna exhibits a focused directional radiation pattern with a dominant main lobe and reduced side lobes.

11) The normalized radiation pattern demonstrated that the antenna radiates maximum power along preferred angular directions, validating its suitability for directional terrestrial broadcasting and satellite communication applications.

12) The compact geometrical structure of the isosceles triangular antenna provides reduced physical size while maintaining good radiation performance and high efficiency.

13) The symmetrical triangular geometry contributed to balanced current distribution, improved phase stability, and enhanced electromagnetic radiation characteristics.

14) The study confirmed that the Method of Moments provides accurate and reliable numerical solutions for the analysis and prediction of the electrical and radiation characteristics of triangular loop antennas.

15) Overall, the research established that the proposed isosceles triangular loop antenna is efficient, compact, highly directional, and suitable for terrestrial broadcasting and satellite communication systems.

6. Conclusions

This study presented the design of an isosceles triangular loop antenna for terrestrial broadcasting and satellite communication using the Method of Moments. The research objectives were successfully achieved, as outlined in the methodology and supported by the results obtained. The isosceles triangular loop antenna demonstrated directional characteristics, as evidenced by a directivity value of 0.9375. At an operating frequency of 9.32 MHz, with one turn of wire and a perimeter of 24.12 cm, the antenna radiated a total power of 116.1 W. With a radiation resistance of 323.2 Ω and a loss resistance of 8.07 Ω, the antenna achieved an efficiency of 86.5%. These results indicate that the proposed isosceles triangular loop antenna exhibits high directivity and is therefore suitable for satellite communication applications, where efficient long-distance signal transmission depends heavily on antenna directivity. This research successfully presented the design and electromagnetic analysis of an isosceles triangular loop antenna for terrestrial broadcasting and satellite communication applications using the Method of Moments (MoM). The study achieved its objectives by determining the electrical, geometrical, and radiation characteristics of the antenna through analytical computation and MATLAB-based simulations.

The numerical results obtained demonstrated that the antenna resonated effectively at a frequency of 9.328 MHz with a wavelength of 32.16 cm. The antenna exhibited a radiation resistance of 323.2 Ω and a relatively low loss resistance of 36.24 Ω, resulting in a high radiation efficiency of 86.5%. The gain of 1.8758 dBi and directivity value of 0.9375 confirmed that the antenna possesses directional radiation characteristics suitable for focused signal transmission.

The graphical results obtained from the Method of Moments showed stable current and phase current distributions along the triangular loop structure, validating the effectiveness of the adopted numerical technique. The radiation pattern plots further confirmed that the antenna radiates electromagnetic energy predominantly in preferred directions with reduced side lobes, making it suitable for long-distance terrestrial broadcasting and satellite communication systems. The compact geometry of the isosceles triangular loop antenna provides structural simplicity, reduced physical size, and efficient radiation performance. The symmetrical triangular configuration also contributed to balanced current distribution and improved electromagnetic behavior. Based on the numerical and graphical results obtained, the study concludes that the proposed isosceles triangular loop antenna is efficient, compact, highly directional, and capable of providing reliable radiation performance for modern wireless communication applications. Furthermore, the Method of Moments proved to be an accurate and reliable computational technique for analyzing and predicting the performance of wire-loop antenna structures.

Conflicts of Interest

The authors declare no conflicts of interest.

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