https://doi.org/10.21122/2227-1031-2026-25-1-14-19

UDC 378

Design and Fabrication of Optimized Folded Dipole Antenna in MHz

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Abstract. One of the key operating bands for wireless communication is the VHF (Very High Frequency) band. This band accommodates a variety of applications within its operational frequency range, such as Land Mobile, FM/TV Broadcast, amateur radio etc. Consequently, it is essential to explore Antenna designs that are suitable for this band. This paper concentrates on the dipole folded antenna design at 100 MHz frequency. Simulations, fabrication, and testing have been conducted. This paper presents a novel model, along with the implementation of a folded dipole antenna optimized for military vehicular applications in the VHF band (30–300 MHz). The proposed antenna achieved a measured resonant frequency of 98 MHz, a return loss of –28 dB, and a VSWR of 1.07, which closely corresponds with both simulated and theoretical results. Furthermore, the antenna demonstrates a wide operational bandwidth of 12 MHz while maintaining a compact structure suitable for vehicles (~2.9 m). This combination of enhanced impedance matching, stable bandwidth, and field-ready fabrication distinguishes it from traditional folded dipole designs used in the VHF range. We have compared the S_{11} plots of the simulated results and the fabricated results. The characteristics of a folded dipole antenna are comparable to those of a dipole Antenna, and HFSS software can be utilized to design and assess it. At the conclusion of the investigation, the simulated return loss result for the folded dipole antenna aligns well.

Keywords: folded dipole, HFSS, military, vehicular, VHF band

For citation: Mishra A. K., Patil D. P. (2026) Design and Fabrication of Optimized Folded Dipole Antenna in MHz. *Science and Technique*. 25 (1), 14–19. https://doi.org/10.21122/2227-1031-2026-25-1-14-19

Проектирование и изготовление оптимизированной складной дипольной антенны в МГц

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Реферат. Одним из ключевых рабочих диапазонов для беспроводной связи является диапазон очень высоких частот (ОВЧ). Этот диапазон частот подходит для различных применений, таких как наземная мобильная связь, FM/телевещание, любительская радиосвязь и т. д. Следовательно, важно изучить конструкции антенн, которые подходят для этого диапазона. В данной работе основное внимание уделяется проектированию дипольной складной антенны на частоте 100 МГц. Были проведены моделирование, изготовление и тестирование. В статье представлена новая модель, а также реализация сложенной дипольной антенны, которая оптимизирована для применения в военной технике в диапазоне ОВЧ (30–300 МГц). В предложенной антенне измерены резонансная частота 98 МГц, коэффициент отражения –28 дБ и коэффициент стоячей волны по напряжению (КСВН) 1,07, что полностью соответствует как результатам моделирования, так и теоретическим данным. Кроме того, предлагаемая антенна демонстрирует широкую рабочую полосу пропускания 12 МГц, сохраняя при этом компактность, что позволяет использовать ее в транспортных средствах (~2,9 м). Сочетания улучшенного согласования импеданса, стабильной полосы пропускания и возможности изготовления в полевых условиях являются характеристиками, которые отличают рассматриваемую антенну от традиционных конструкций сложенных диполей, используемых в диапазоне ОВЧ. Проведен сравнительный

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анализ графиков S_{11}, на которых отображены результаты моделирования и изготовления. Характеристики сложенной дипольной антенны сопоставимы с характеристиками обычной дипольной антенны, и для ее проектирования и оценки можно использовать программное обеспечение HFSS. Проведенные исследования показывают, что результаты моделирования коэффициента отражения для сложенной дипольной антенны хорошо согласуются с полученными данными.

Ключевые слова: сложенный диполь, система моделирования высокочастотных структур, военный, автомобильный, диапазон очень высоких частот

Для цитирования: Мишра, А. К. Проектирование и изготовление оптимизированной складной дипольной антенны в МГц / А. К. Мишра, Д. П. Патиль // *Наука и техника*. 2026. Т. 25, № 1. С. 14–19. https://doi.org/10.21122/2227-1031-2026-25-1-14-19

Introduction

Many military and civilian technologies depend on effective wireless communication. The antenna design must adhere to stringent specifications due to the variety of environments and situations in which these applications are anticipated to operate. Robotic communications and aerial communications are two examples of these uses.

It is known that the channel at lower frequencies is much simpler than the one at higher frequencies [1]. Consequently, the signal transmission experiences minimal attenuation and can pass through obstructions like walls. Consequently, there is now more interest in these operating frequency bands. Interest in VHF communications has grown as a result of the creation of small VHF antenna designs [2–5]. A dipole folding antenna design for VHF communications is examined in this research [6–7].

VHF is the term employed by ITU to describe radio waves that travel in frequency range of 30 to 300 MHz (Table 1). The wavelength range of these radio frequency waves is relatively high, ranging from 1 to 10 m. The ITU has designated frequencies below VHF band as high frequency, or HF, band and frequencies above VHF band as ultra-high frequency, or UHF, band of operation. Ground-induced reflections and line-of-sight (LoS) paths are primary propagation methods in VHF band. In contrast, there are slight reflections from the top layers of the atmosphere in the HF band. Because VHF waves do not go through the earth, their trajectory does not follow the curvature of the ground. Additionally, they experience signal attenuation as a result of obstruction from hills, mountains, and other natural features. Refractions from the atmosphere are possible. These refractions are typically relatively weak, however. The radio waves in the VHF band travel approximately 100 miles beyond the horizon due to a combination of several processes. Indoor receivers can pick up these waves since they can readily go through walls. The quality of the received signal is impacted by multipath, which is caused by reflections from tall buildings and other objects in an urban setting. Antennas for the VHF band can be made small enough to put on cars. These antennas typically have dimensions ranging from 25 cm to 2.5 m.

Table 1

Radio frequency bands with applications [8]

Name	Frequency range	Applications
Low frequency (LF)	30 to 300 kHz	Navigation, time standards
Medium frequency (MF)	300 kHz to 3 MHz	Marine/aircraft navigation, AM broadcast
High frequency (HF)	3 to 30 MHz	AM broadcasting, mobile radio, amateur radio, shortwave broadcasting
Very high frequency (VHF)	30 to 300 MHz	Land mobile, FM/TV broadcast, amateur radio
Ultra-high frequency (UHF)	300 MHz to 3 GHz	Cellular phones, mobile radio, wireless LAN, PAN
Super high frequency (UHF), millimeter-wave range	3 to 30 GHz	Satellite, radar, backhaul, TV, WLAN, 5G cellular
Extremely high frequency (EHF)	30 to 300 GHz	Satellite, radar, backhaul, experimental, 5G cellular
Terahertz, tremendously high frequency (THF) or far infrared (FIR)	300 GHz to IR	R & D, experimental

Bidirectional communication in automobiles, walkie-talkies, and airplanes is accomplished via VHF transmissions. Fiberglass whips, rubber ducky antennas, and yagi antennas are a few examples of VHF band antennas. These antennas can, however, be rather massive in comparison to those in the upper bands.

Methods

The folded antenna (Fig. 1) is composed of a basic dipole whose ends are connected by a conductor, creating a loop. The antenna's name comes up. Being fed with a balanced feeder is essential for the folded dipole antenna to function as a balanced antenna [9]. If feeder is unbalanced, transfer to perform balancing is needed (e. g., balun).

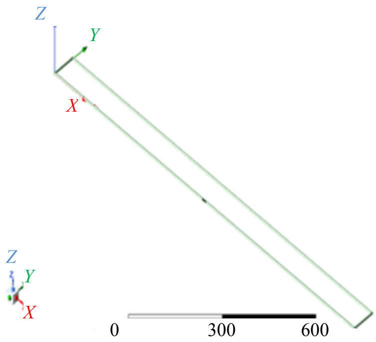

Fig. 1. Antenna Design

$$W = 2d = 4R, \qquad (1)$$

The relation between the width of folded dipole antenna to diameter of corresponding cylindrical dipole is where d is the diameter and R is the equivalent radius of the cylindrical dipole. The extra portion of the antenna is created by the use of wire or rod that has same d as basic dipole. There are two key benefits to folded dipole antennas. First, the folded dipole antenna can supply a match to the feeder if the dipole's impedance drops as a result of parasitic elements, for example. Second, the folded dipole antenna's bandwidth is increased due to its flat frequency response amplitude. Further, folded antennas can be used on their own or can be coupled with other antennas [10]. The folded antenna is thoroughly studied. The key parameters of the antenna that are studied are the impedance plots, S11 (return loss), and VSWR [11, 12].

Simulation of Folded Dipole Antenna. Calculation of dimensions such as λ, length of antenna (L), radius of antenna, and gap [13]. Following is the stepwise procedure for design of an HF band antenna:

at f = 100 MHz

$$\lambda = \frac{c}{f} = \frac{3 \cdot 10^8}{100 \cdot 10^6} = 3 \text{ m}; \qquad (2.1)$$

length of antenna

$$L = \frac{\lambda}{2} = \frac{3}{2} = 1.5 \text{ m}; \qquad (2.2)$$

radius

$$(r) \le \lambda/120 \le 3/120 \le 0.025 \text{ m}; \qquad (2.3)$$

gap (gap feeding) = dipole radius × 2 =

$$= \frac{3}{120} \cdot 2; \qquad (2.4)$$

$$\text{ground} = \frac{c}{2f}\sqrt{\frac{1+\text{er}}{2}} = 1.5 \text{ m for er} = 1. \qquad (2.5)$$

Impedance can be described as the ratio of the input port's voltage to its current. Fig. 2 displays impedance for suggested antenna. The graphic displays real and imaginary parts of suggested antenna design for 40–160 MHz frequency range. At resonant frequency 100 MHz, impedance is 49.75 Ω.

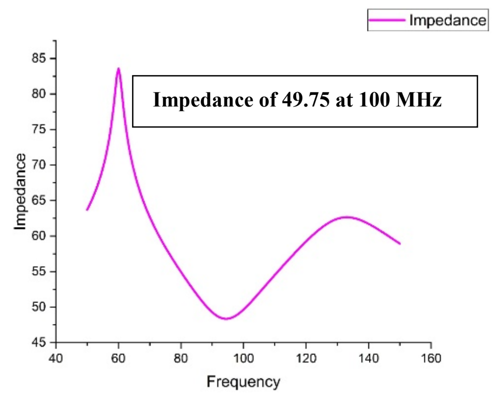

Fig. 2. Impedance of the proposed antenna

After simulation, we obtained the return loss of the folded dipole antenna with a range of frequencies from 50 to 150 MHz. The peak resonating frequency is 100 MHz, as shown in Fig. 3.

Also, we obtain VSWR value of folded dipole antenna as 1.05 as displayed in Fig. 4.

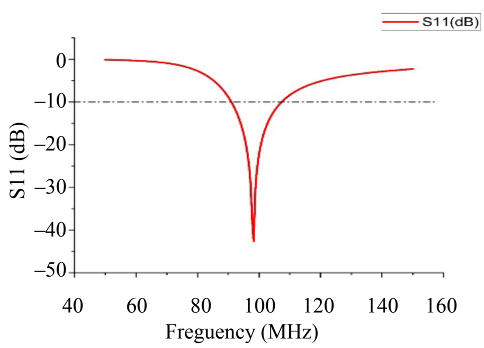

Fig. 3. Return loss of folded dipole antenna

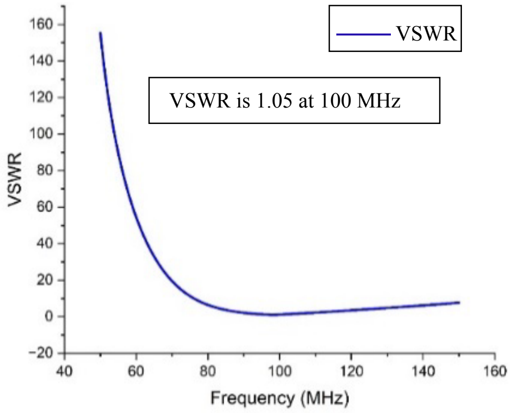

Fig. 4. VSWR of proposed antenna (simulated)

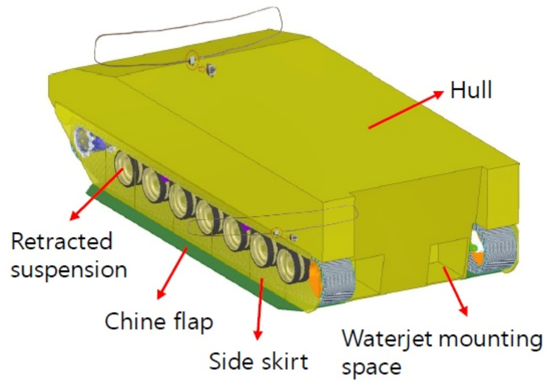

Fig. 6. Folded dipole antenna installation on army tank [16]

Fabrication and Testing of Folded Dipole Antenna. The volume of the radiating mechanism is directly proportional to the antenna's gain-bandwidth product [13]. In the HF frequency regions, where the wavelengths range from 10–100 m, this is a serious concern [14–15].

Physically, the military vehicle antenna, depicted in Fig. 5, is cylindrical with following dimensions:

1) material – copper;

2) cylindrical wire dimensions: radius – 3 mm; height – 81 mm; feeding dimension: 6 mm; total dimensions with feeding: 2907 mm; with 6 mm feeding sided total length – 1372.5 mm; and width – 81 mm;

3) SMA: 4-hole flange SMA connector female 50 ohm.

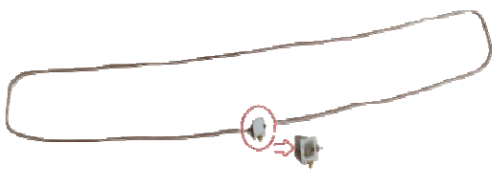

Fig. 5. Fabrication of folded dipole antenna

Testing of folded dipole antenna (Fig. 6) has been done on VNA. VNA details are as follows: VNA Name: Keysight Technologies FieldFox Vector Network Analyzer, Model name: N9921A Freq Range: 100 kHz to 6 GHz.

In Fig. 7, after testing the above antenna, we obtained a resonant frequency of 98.28 MHz and a return loss of –28 dB. We get a bandwidth of 12 MHz and a return loss of –28.89 dB.

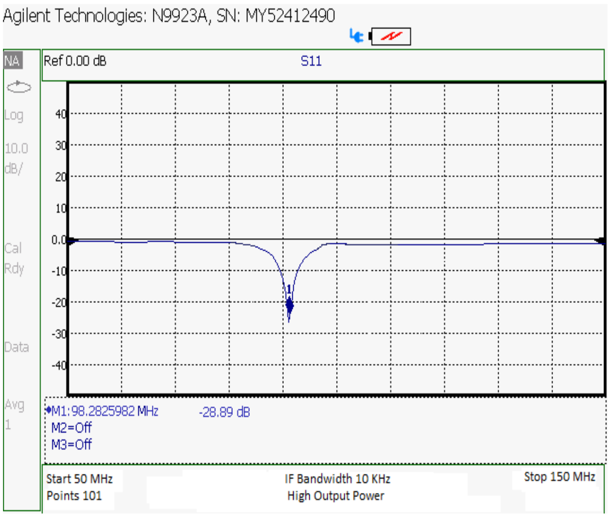

Fig. 7. Measured S11 (return loss)

Results and Discussions

We have simulated, fabricated, and tested a folded dipole antenna. Simulation is done on HFSS. Fabrication is done using copper wire with 4-hole flange SMA connector female 50 ohm. And it is tested on VNA. Following results are obtained.

Table 2 presents a comparison of measured values, simulated values, and theoretical values for different parameters. It is observed from the Table 2 that the resonant frequency of the simulation, as measured, matches the theoretical value. Return loss of measured value of the proposed antenna is high as compared with simulated results. VSWR simulated, measured value is the same as theoretical value. Bandwidth lies in a stipulated range.

Table 2

Comparison of measured value and simulated value of different parameters

Sr. No	Results	Freq (MHz)	R.L. (dB)	VSWR	Bw (MHz)
1	Simulated results	98.12	–42.65	1.05	16.02
2	Measured results	98	–28.89	1.07	12
3	Theoretical values	100	< –10	>1	5 to 15

Here, we have compared the S_{11} plots of the simulated result and the fabricated result. Graph shows the comparison of measured return loss vs simulation return loss. The simulated return loss result for the folded dipole antenna correlates well and determined outcome is represented in Fig. 8.

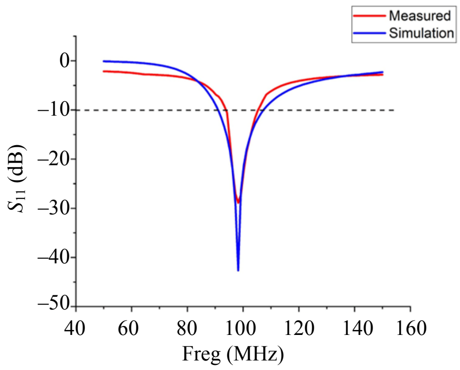

Fig. 8. Return Loss of folded dipole antenna

Novelity

Innovation. This study presents a novel model, along with the implementation of a folded dipole antenna optimized for vehicular military applications in the VHF band (30–300 MHz) [17–21]. The innovation lies in the end-to-end approach, which includes simulation using HFSS, physical fabrication utilizing copper with SMA integration, and validation via VNA testing. The proposed antenna achieved a measured resonant frequency of 98 MHz, return loss of –28 dB, and VSWR of 1.07, closely aligning with simulated and theoretical results. Furthermore, the antenna demonstrates a wide operational bandwidth of 12 MHz while maintaining a compact vehicular-compatible structure (~2.9 m). This integration of enhanced impedance matching, stable bandwidth, and field-ready fabrication differentiates it from traditional folded dipole designs used in the VHF range.

Novelty. a) application-specific adaptation: the folded dipole is tailored for military vehicular communication, balancing performance and size.

b) enhanced bandwidth and return loss: achieving a 12 MHz bandwidth with –28 dB return loss is a significant improvement over many classical folded dipole antennas (typically ~5–10 MHz bandwidth in this frequency range).

c) validated real-world deployment: our work includes fabrication and real-world validation, which adds to its practical value.

d) integrated end-to-end approach complete cycle from simulation (HFSS) → fabrication (copper with SMA connector) → real-world testing (VNA) with close alignment between simulated and measured results (98 vs 98.12 MHz resonance).

Conclusion

This work presents the design and analysis of a folded dipole antenna. This paper addresses the simulation, fabrication, testing, and validation of a folded dipole antenna. The values of VSWR and Bandwidth are measured, and it was found that the values of these parameters for simulation and fabrication are approximately identical. Results of simulation and fabrication are compared with theoretical values, and it is found satisfactory. The design of the antenna has been shown. Various parameters, such as its impedance, S_{11}, gain, and VSWR, are examined. The folded dipole antenna has been simulated, fabricated, and validated.

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Received: 09.10.2025
Accepted: 29.12.2025
Published online: 30.01.2026