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Review on HF Band Vehicular Antenna with NVIS Communication

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Abstract

Antennas play a fundamental role in modern communication systems by facilitating signal transmission and reception across various frequency bands. Each antenna is designed for specific applications based on its operating frequency range. Whether deployed for Car-to-Car Communication or military operations, antennas serve critical functions, with information security being paramount in military contexts. Vehicular antennas typically operate within the L Band, approximately 1 to 2 GHz, relying on satellites for signal communication. However, traditional transmission through the ionosphere faces limitations, notably the skip zone, where signal reception is hindered, leading to communication failures. To address this limitation, Near Vertical Incident Skywave (NVIS) communication has been developed. NVIS utilizes antennas with very high (>75°) radiation angles and low HF frequencies to overcome skip zone challenges. Despite existing research efforts, achieving high radiation efficiency remains a challenge, often due to improper antenna angle settings. Additionally, previous studies have overlooked the importance of narrow beam focusing, crucial for long-range communication and direction finding. This paper aims to enhance antenna performance parameters such as efficiency and gain through the adoption of specific techniques. By optimizing antenna design and configuration, we aim to improve performance for ionospheric communication, particularly in military applications involving data and voice transmission.

Keywords: military communication, NVIS communication, vehicular antennas

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Обзор автомобильных КВ антенн с функцией NVIS-связи

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Антенны играют основополагающую роль в современных системах связи, обеспечивая передачу и приём сигналов в различных частотных диапазонах. Каждая антенна разрабатывается для решения конкретных задач в зависимости от её рабочего диапазона частот. Независимо от того, используются ли они для связи между автомобилями или управления боевыми действиями, антенны выполняют критически важные функции, при этом первостепенное значение для военных применений приобретают соображения информационной безопасности. Автомобильные антенны обычно работают в диапазоне *L*, приблизительно от 1 до 2 ГГц, передавая сигнал через спутники. Однако традиционная передача сигнала через ионосферу связана с рядом ограничений, в частности, с наличием мёртвой зоны, приём сигнала в которой затруднён, что приводит к потере связи. Для борьбы с этим ограничением был предложен метод околовертикального падения ионосферной волны, или NVIS (Near Vertical Incident Skywave). В методе NVIS используются антенны с очень большими (>75°) углами излучения и низкие частоты КВ диапазона, что позволяет преодолеть проблему мёртвой зоны. Несмотря на предпринимаемые исследователями усилия, достижение высокой эффективности излучения остаётся проблемой, часто из-за неверного выбора угла антенны. Кроме того, в предшествовавших исследованиях не уделялось должного внимания проблеме фокусировки узкого луча, имеющей критическое значение для дальней связи и пеленгации. Целью данной статьи является улучшение таких характеристик антенн, как эффективность и коэффициент усиления, путём использования специальной методики. Оптимизация конструкции и конфигурации антенн направлена на улучшение характеристик ионосферной связи, в частности, для военных применений, связанных с передачей данных и речи.

Ключевые слова: военная связь, связь NVIS, автомобильные антенны

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1. Introduction

Vehicular antennas play a crucial role in various communication systems, including car-to-car communication, military vehicles, aircraft, and ships [1]. While these antennas can be designed for the UHF range, using satellite communication raises concerns about data security due to the involvement of different agencies handling the satellite and its data. To overcome this limitation, the high-frequency (HF) band [2, 3] presents a viable alternative.

In the HF band, antenna signals are reflected from the ionosphere. However, this approach has several disadvantages, such as the presence of a skip zone, height limitations for the antenna, multipath fading, and higher power requirements. To address these challenges, the near vertical incidence skywave (NVIS) technique [3, 4, 5] is implemented. NVIS communication differs from traditional HF antennas in the following ways:

• NVIS antennas are designed for high radiation angles (>75°) to maximize skywave propagation.

• An antenna tuning unit (ATU) is used to optimize the antenna's performance.

Furthermore, various NVIS antenna types exist, including dipoles, inverted vees, and unbalanced wires. Among these, unbalanced wire antennas and inverted L-antennas are preferred for vehicle applications due to their ability to radiate along the entire length of the wire when connected at the end at 50 ohms microstrip field line [6].

Antennas play a vital role in our daily lives, enabling signal transmission and reception across various frequency bands. Some of the measures applications where antenna used such as, military applications, information security and wireless devices. Designing antennas in the HF range allows signal transmission and reception through the ionosphere, eliminating the need for satellites and ensuring data security. NVIS communication enables coverage of nearby regions by transmitting signals through the skywave with a high radiation angle (>75°), effectively reducing the skip zone. NVIS offers several advantages, including data and voice communication capabilities, as well as support for disaster relief and military operations [7].

However, the currently available HF band vehicular antennas suffer from limitations such as poor radiation efficiency, resulting in low gain values (less than -20 dBi) and a narrow bandwidth of 24 kHz. The objective of this research is to design HF band vehicular antennas with enhanced parameters, including improved efficiency, gain (better than -20 dBi), and the inclusion of NVIS for nearby region coverage. Additionally, the research focuses on achieving unidirectionality in the antenna by maintaining a high directivity value, which can be accomplished by increasing the effective aperture.

There are several simulated software available for implementation of this project. For example, numerical electromagnetics code (NEC2), computer simulation technology (CST), and high frequency structure simulator (HFSS). Among these HFSS is widely preferred. HFSS uses adaptive meshing, the Finite Element Method (FEM), and stunning graphics to provide you with unmatched performance and understanding for all of your 3D EM challenges. S-Parameters, Resonant Frequency, and Fields are among the parameters that may be calculated using HFSS.

Progression of the manuscript flow discussed in the following manners: Section II of this paper presents a literature survey, furthermore, in section III explains wave propagation and NVIS. Moreover, in section IV highlights the challenges and scope of the proposed work, and in section V focuses on the design and analysis of the presented work for HF band vehicular antennas. Finally, in section VI illustrates the conclusion of the proposed work.

2. Literature review

This section presents a review of the existing literature related to HF band vehicular antennas and NVIS communication. In this sections we highlighted the key contributions, limitations, and gaps that motivate the current research.

2.1. HF band vehicular antennas

In [2], the authors designed an inverted *L* antenna for vehicular HF communications. This antenna achieved a gain of -24 dBi and a bandwidth of 24 kHz. The study suggests that reducing the quality factor (Q) can increase the bandwidth, while an offset feed can enhance the gain. However, the achieved gain and bandwidth values are relatively low, indicating the need for further improvements.

Authors in [8], proposes an antenna with a higher gain of -18.1 dBi by using two radiating elements that function as parallel capacitors.

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The inclusion of a high-core inductor further enhances the gain to -17.9 dBi. The study also investigates the use of capacitive loading to reduce antenna height and improve bandwidth, as well as the incorporation of chip inductors to reduce antenna size. However, the authors emphasize the importance of using high-Q chip inductors and capacitors to maintain good radiation efficiency.

Authors in [9], have implemented HF Band vehicular antenna with NVIS. This antenna achieved the -10 dB frequency between 3 to 10 MHZ to reach a wide range of 200 KM. NVIS is utilized for communication in places without a telecommunications infrastructure or in places where a major disaster, like the flooding in New Orleans in 2005, destroys the infrastructure that already exists. Again Authors in [9], have presented a NVIS study carried out in Netherlands.

Table 1

Comparison of various paper studied on HF band vehicular antenna

Methodology	Main findings	Limitations
The methodology involves the development of an HF loop antenna for two-way communications up to 300 km, contrasting it with traditional methods and considering the limitations of NVIS propagation [10]	The development of an HF loop antenna allows for two-way, i. e. Tx. and Rx. communication up to 300 km, with NVIS propagation being crucial and limited to the frequency band of 1.5 MHz to 12 MHz	• The study is limited to the frequency band of interest between 1.5 MHz and 12 MHz due to the dependence of NVIS propagation on the ionosphere. • The study does not explore other frequency bands outside the range of 1.5 MHz to 12 MHz. • The study does not address potential challenges or limitations of using the HF loop antenna in different environmental conditions or geographical locations
The methodology involved designing low-profile, wide-band, high-frequency antennas for military vehicles, fabricating a full-scale prototype, and conducting stand-alone measurements and tests with an experimental WB HF radio to validate the design approach [11]	The design of low-profile, wideband, high-frequency antennas for military vehicles was successful in meeting performance requirements while maintaining a compact profile. A full-scale prototype was created and tested with a military vehicle, confirming the expected impedance behavior and validating the design approach. The antenna demonstrated flexibility in adapting to various communication conditions due to its diverse operation modes	Design challenges related to small electrical size and mounting constraints, challenges in the diverse environment in the near field. No explicit mention of limitations or suggestions for further research
The methodology involved identifying the factors contributing to rotor modulation and proposing the use of specific antennas to address the issue [12]	Antennas mounted on helicopters for HF NVIS communication face severe rotor modulation near resonant frequencies. The use of two towel-bar antennas can help reduce the drop in gain caused by hub currents. Despite the improvement in gain due to the antennas, the variation in gain caused by parasitic radiation from the rotor blades persists	Limited scope to helicopters with tandem main rotors, proposed solution only addresses drop in gain due to hub currents, no validation of solution in real-world scenarios

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The methodology involves examining operational requirements, determining necessary antenna characteristics, and reviewing simple antenna designs for suitability in lightweight transportable systems [13]	HF radio is increasingly used for short and medium-distance communications, especially for mobile or transportable stations. The paper aims to determine the characteristics suitable antennas must provide for these communications. Simple antenna designs are reviewed for their suitability in lightweight transportable systems	• Lack of familiarity of engineers with the exact characteristics needed for antennas in HF radio communications. • The need to determine the characteristics that suitable antennas must provide
The methodology involved applying characteristic mode analysis to vehicular antennas, focusing on exciting horizontal electric dipole current distribution and using edge port excitation to achieve bandwidth improvements [14]	Low-profile vehicular antennas in the NVIS frequency range are inefficient and narrowband due to their small size. The widest bandwidth is obtained by exciting the horizontal electric dipole current distribution on the vehicle. Achieving a bandwidth of 24 kHz above realistic grounds comes with the trade-off of very low gain at 2 MHz	Study limited to NVIS frequency range Trade-off between bandwidth and gain
The methodology involved using the Numerical Electromagnetics Code (NEC) antenna modeling program to obtain and analyze data on the performance, current distributions, and radiation patterns of high-frequency (HF) tactical generic antennas [15]	The main findings include the performance characteristics of different high-frequency tactical antennas such as groundwave communication, NVIS performance, and suitability for different ranges of communication	Limited generalizability to other antenna types, lack of discussion on performance in different environmental conditions, absence of comparison with other antenna models, no mention of limitations of the NEC antenna modeling program
The methodology involved optimizing an antenna for NVIS applications on a vehicle, focusing on a vertically orientated loop configuration, capacitive loading effects, and developing a transmission line model for design [16]	- NVIS antennas for vehicle mounting have limited development scope due to size constraints at typical frequencies. - Vertically orientated loop antennas are confirmed to be the most effective configuration. - Capacitive loading of the loop has a desirable effect on current distribution and energy radiation towards the zenith	Limited scope for development within typical NVIS frequencies and vehicle sizes. Focus on a specific vehicle size may limit generalizability

2.2. NVIS antennas

InIn [4], the authors designed electrically small antennas for NVIS communications, achieving a gain of -18.1 dBi by utilizing two radiating elements as parallel capacitors and incorporating high-Q air-core inductors. Similar to [8], capacitive loading is employed to reduce antenna height and improve bandwidth, while chip inductors are used in printed monopole antennas to reduce size [17]. The study highlights the importance of using high-Q chip inductors and capacitors to maintain good radiation efficiency. The work in [5] focuses on designing an array of antennas for near vertical-incidence

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Skywave (NVIS) communication. The authors report an increase in efficiency by 1 dB and a gain increase of 3 dB for a two-dipole array, while a four-dipole array achieves optimized directivity (efficiency between 2.6 dB to 3 dB, D = 0.2 dB, and gain = 2.8 dB to 3 dB). The study suggests that elevating the antenna's height or operating frequency can significantly improve efficiency. Research conducted in the Netherlands [9] explores the performance of horizontal dipole antennas above ground for NVIS applications [18, 19, 20], considering antenna heights between 0.18λ and 0.22λ.

While the existing literature provides valuable insights into HF band [21] vehicular antennas and NVIS communication [22, 23], there is still a need for further improvements in terms of radiation efficiency, gain, bandwidth, and unidirectionality. Additionally, the integration of NVIS capabilities with vehicular antennas remains an area that requires further exploration and optimization.

3. Sky Wave Propagation and NVIS

3.1. Sky Wave Propagation

The propagation of sky waves is caused by the internal reflection of electromagnetic waves by the ionosphere. The ionosphere is a region of the Earth's atmosphere, extending from approximately 50 km to 400 km above the surface, where molecules are ionized by solar radiation. This ionization process enables the reflection and refraction of radio waves in the high-frequency (HF) range, typically between 3 and 30 MHz [23, 24].

Figures 1 and 2 illustrated the Sky wave propagation and ionization process in ionosphere. However, Figure 3 illustrates various wave propagation modes, including ground wave, sky wave, and space wave propagation as observed in the Figures 3.

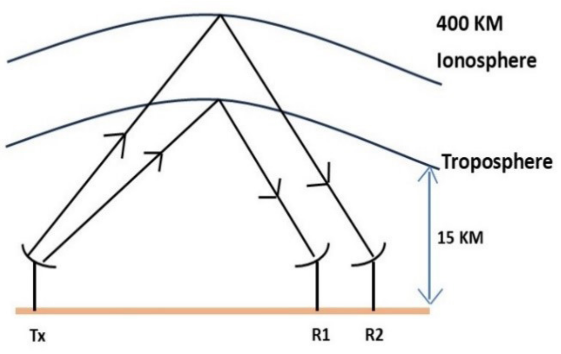

Figure 1 – Sky wave propagation

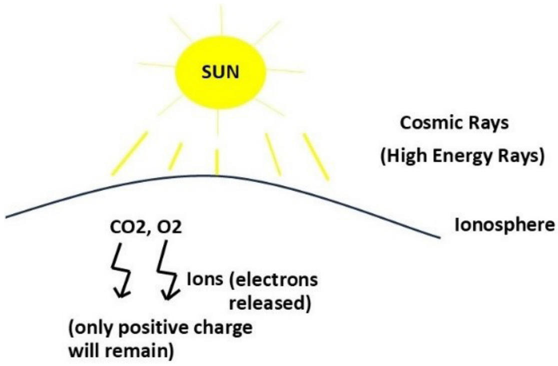

Figure 2 – Ionization process in ionosphere

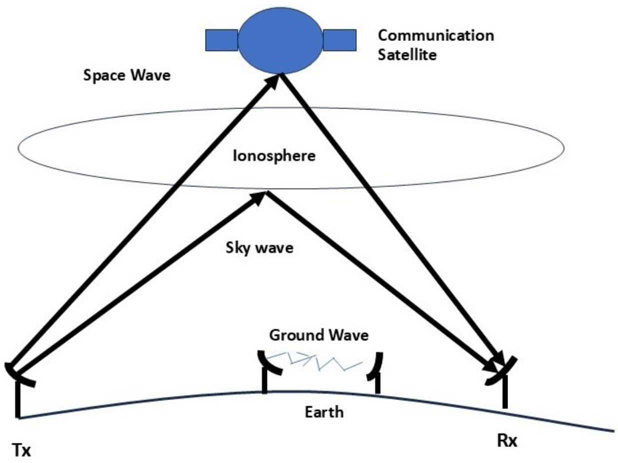

Figure 3 – Ionization process in ionosphere

Figure 4 shows the classification of the Earth's atmosphere into different layers: the troposphere, stratosphere and ionosphere.

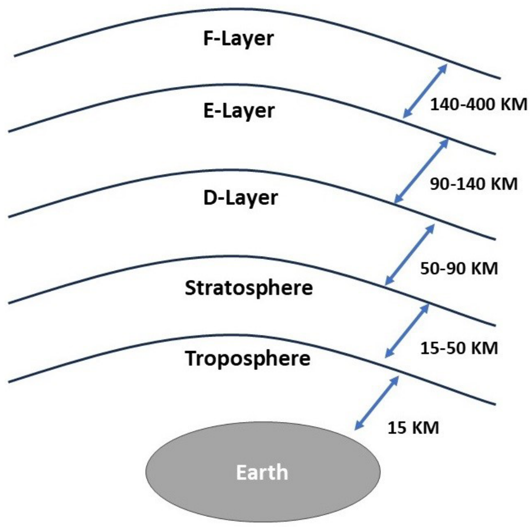

Figure 4 _ Different layers of atmosphere

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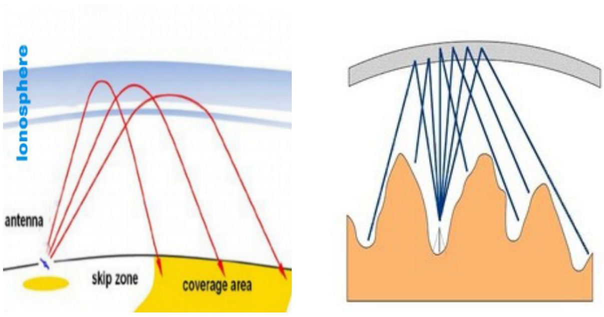
The ionosphere consists of several layers, including the *E* layer, *F* layer, and *D* layer. The *D* layer of the ionosphere absorbs radio signals, helping to determine the minimum frequency that can propagate through the ionosphere. The *F* layer, on the other hand, refracts signals, playing a crucial role in determining the maximum usable frequency [17]. The incident angle of the radio wave also influences how far the signal can travel before being refracted back to Earth.

Skip zone

One important concept in ionosphere propagation and radio communications is the skip zone. It refers to the region where radio signals cannot be received directly from the transmitter due to the refraction of waves by the ionosphere. Beyond this zone, the refracted signals can be received, enabling long-distance communication [29].

3.2. Near vertical incidence skywave

NVIS is a technique used in high-frequency (HF) communication that involves transmitting radio signals at very high radiation angles (>75°) using specialized antennas [36, 37]. NVIS takes advantage of the sky wave propagation phenomenon, where radio waves are refracted by the ionosphere and can be received at locations beyond the skip zone [7]. Figure 5 illustrates the difference between a vehicular antenna operating in the HF Band with NVIS and without NVIS.



a *b*

Figure 5 – Vehicular antenna in HF range without NVIS (*a*) and vehicular antenna in HF range with NVIS (*b*)

NVIS offers several advantages over traditional HF communication techniques:

1. *Extended coverage*: NVIS can provide communication coverage within a radius of several kilometers, making it suitable for various applications, such as including military operations, disaster relief efforts and military surveillance in remote areas.

2. *Low-power operation*: NVIS antennas can operate at relatively low power levels, making them suitable for portable applications where power consumption is a concern.

3. *Omnidirectional coverage*: NVIS antennas typically provide omnidirectional coverage, ensuring communication in all directions. However, antenna orientation is crucial to achieve the desired radiation pattern.

4. *Reduced multipath fading*: by transmitting signals at high radiation angles, NVIS reduces the effects of multipath fading, which can degrade signal quality in traditional HF communication.

5. *Lower probability of intercept*: due to the low-power operation and vertical radiation pattern, NVIS communication has a lower probability of being intercepted, making it beneficial for secure communications.

6. *Jamming resistance*: NVIS signals are difficult to jam via ground wave propagation, increasing the reliability of communication in contested environments.

3.3. Near vertical incidence sky wave deployment

The deployment of communication systems utilizing NVIS technology involves several key steps [27]:

1. *Frequency selection*:

• Choose the appropriate frequency range for NVIS transmission, typically within the HF band of 3–10 MHz, as these frequencies can reflect off the ionosphere at steep angles.

2. *Antenna installation*:

• Install an antenna specifically designed for NVIS communication, capable of transmitting signals at near-vertical angles (close to 90°).

• Wire antennas, such as dipoles or loops, are commonly used for NVIS deployment.

• Position the NVIS antenna at a reasonable height above the ground, typically between 1 and 10 m (3 and 33 feet). This height ensures that the radio waves return to the Earth's surface at acute angles, enabling effective NVIS communication.

3. Transceiver setup:

• Set up the HF transceiver and any other required equipment for NVIS communication.

• Configure the transceiver's power output, modulation parameters, and operating frequency range.

4. *Power Requirements*:

• NVIS communication requires relatively low power output compared to other communication techniques due to its limited range.

• Typical power requirements range from a few watts to a few hundred watts, depending on the equipment used and the specific application.

NVIS deployment finds applications in various scenarios where reliable short-range communication is required, such as:

• Military operations, especially in areas with challenging terrain or obstructions that limit line-of-sight communication.

• Emergency communication and disaster response efforts, where traditional communication infrastructure may be disrupted or unavailable.

• Remote or rural areas without access to other communication networks.

• Tactical communication in environments where stealth and low probability of intercept are crucial.

By following the proper deployment steps and utilizing the appropriate equipment, NVIS communication can provide a reliable and secure means of communication over short to medium ranges, enabling critical information exchange in challenging environments.

4. Challenges and scopes

Designing vehicular antennas for the HF band with NVIS communication presents a range of challenges and opportunities that require careful consideration and innovative solutions. This section highlights the key areas that demand attention and further research.

4.1. Material selection

• Selecting the most appropriate material for antenna design is a critical factor that can significantly impact the antenna's performance and efficiency. The choice of material directly influences the conductivity, which in turn affects radiation efficiency and overall antenna performance.

• Copper, aluminum, and graphene are among the potential materials under consideration. While copper (conductivity: 58 MS/m) and aluminum (conductivity: 35 MS/m) are traditional choices, graphene (conductivity: 100 MS/m) has emerged as a promising alternative due to its superior conductivity.

• Graphene’s exceptional conductivity makes it a preferred material fo potentially enhance radiation efficiencyr vehicular antenna design, as it can and improve overall antenna performance.

4.2. Antenna design challenges

• Achieving high radiation angles, typically greater than 75°, is crucial for maximizing skip distance coverage in NVIS communication [7]. This angular requirement presents a significant design challenge, as it necessitates careful optimization of the antenna's geometry and positioning.

• Improving key antenna parameters, such as gain, bandwidth, and directivity, is another critical challenge. These parameters are essential for ensuring reliable and efficient communication, especially in military applications where long-range and directional communication is often required [1].

• Incorporating inductors (L) and capacitors (C) into the antenna design has been proposed as a potential solution to enhance bandwidth and gain, respectively [8]. However, the integration of these components requires careful consideration of their values and placement to avoid compromising other performance metrics.

• Employing multi-arming techniques and offset feeds have been explored as means to increase bandwidth and gain, respectively [2, 19]. However, the effectiveness of these techniques may vary depending on the specific antenna design and operating conditions.

4.3. Performance limitations

• Despite ongoing research efforts, existing vehicular antennas in the HF band often suffer from low gain values, typically around -20 dBi, due to poor radiation efficiency [1, 2]. Overcoming this limitation is crucial for achieving reliable and long-range communication.

• Ensuring the proper adjustment of the antenna's radiation angle is vital for reducing the skip zone, a region where signal reception is compromised [7]. Accurate angle adjustment is essential for maximizing the coverage area and enhancing communication reliability.

• Achieving a narrow beam pattern is essential for long-range communication and direction-finding applications. A narrow beam pattern not only improves signal strength and range but also enhances the antenna's directional capabilities, which are critical in military and other specialized applications.

4.4. Simulation and modeling

• Accurate simulation and modeling of metallic antennas are crucial for design optimization and performance prediction. Computational techniques and specialized software tools play a vital role in this process, allowing researchers and engineers to evaluate various design configurations and refine antenna parameters before physical prototyping.

• Software tools like 4NEC2, CST, HFSS have been widely used for simulating and analyzing HF band vehicular antennas [30]. These tools enable detailed modeling of antenna structures, accounting for factors such as material properties, geometric configurations, and operating conditions.

• Reliable simulation and modeling techniques are essential for identifying potential issues, optimizing antenna designs, and exploring innovative solutions to address the challenges associated with vehicular antennas in the HF band with NVIS communication [28].

The main challenges in designing vehicular antennas for the HF band with NVIS communication involve achieving high gain values (better than -20 dBi) while maintaining a narrow beam pattern and adequate bandwidth. Additionally, the integration of NVIS capabilities, the selection of appropriate materials, and the accurate modeling and simulation of antenna designs are critical factors that require careful consideration and ongoing research efforts. It is important to note that addressing these challenges not only contributes to the advancement of vehicular antenna technology but also has broader implications for various applications, including military operations, emergency communication, and disaster response efforts. Overcoming these challenges can lead to improved communication reliability, increased range, and enhanced directional capabilities, ultimately enabling more effective and secure information exchange in challenging environments.

5. Design and analysis of HF band antenna

5.1. Parameters and performance enhancement techniques of vehicular antenna in HF band

Two parameters on which we are working. These are as follows: 1. Gain, and 2. Radiation efficiency.

5.1.1. Gain

Gain is classified into two types [6]:

• Directive Gain,

Gd = Radiation Intensity in particular direction / average radiated power;

• Power Gain,

Gp = Power density radiated in a particular direction by the test antenna / Power density radiated in that direction by an isotropic antenna.

Directive gain and power gain are identical except that power gain takes into account the antenna losses.

So, Gp = η Gd (η lies between 0 and 1).

5.1.2. Gain enhancement techniques

a) With offset feed. Due to offset feed, uniform current distribution takes place. So, maximum radiation efficiency is achieved. It can be proved from this formula G = η D

With η high, the gain will be high [1].

b) Proper impedance matching also gives better gain due to improvement in η [1].

Example:

$$\Delta f = f_r/Q, \quad (1)$$

Δf = 600 KH; z = 0.600 MHz; f_r = 30 MHz.

$Q = f_r/\Delta f$.

Therefore, Q = 50.

And, if Δf = 24 KHz, f_r = 30 MHz.

Then, $Q = f_r/\Delta f = 30\cdot10^6 / 24\cdot10^{3} =$ 1250.

It is observed that for the HF band antenna, as the frequency range is between 3 MHz to 30 MHz, Q changes from 125 to 1250 i. e. 10 times. It is observed that when Q changes 10 times, gain increases by 10 dB [30].

5.1.3. Radiation efficiency

Radiation efficiency is a crucial parameter in antenna design, representing the ratio of the power radiated by the antenna to the total input power. It is a measure of how effectively the antenna converts the input power into radiated electromagnetic waves. For vehicular antennas in the HF band with NVIS communication, optimizing radiation efficiency is essential to ensure reliable and efficient communication.

The theoretical formula for radiation efficiency (η) is given by:

$$\eta = P_r / P_t; \quad (2)$$

$$\eta = P_r / (P_r + P_l).$$

Therefore,

$$\eta = R_r / R_r + R_l, \quad (3)$$

Where P_r is the radiated power; P_t is the total input power; P_l represents the power lost due to various factors (e. g., ohmic losses); R_r is the radiation resistance; R_l is the ohmic resistance.

5.1.4. Efficiency enhancement techniques

1. *Optimizing radiation and loss resistance*

The radiation efficiency can be expressed as:

$$\eta = 100 / (1 + R_{loss} / R_{rad}). \quad (4)$$

For high radiation efficiency (η), the ratio of the loss resistance (R_{loss}) to the radiation resistance (R_{rad}) should be minimized. This can be achieved by reducing the loss resistance and increasing the radiation resistance. Example: for a two-wire dipole antenna in free space, the radiation resistance (R_{rad}) is proportional to the square of the length of the antenna. By increasing the length of the dipole, the radiation resistance increases, leading to an enhancement in radiation efficiency.

2. *Optimizing inductance and capacitance values*

The bandwidth efficiency (ηB) is given by:

$$\eta B = \frac{1}{2\pi\sqrt{LC}}, \quad (5)$$

where, L and C are the inductance and capacitance values, respectively. To achieve high radiation efficiency, the values of L and C should be kept low, resulting in a high-quality factor (Q). This technique is particularly relevant for electrically small antennas commonly used in vehicular applications.

3. *Antenna orientation and frequency dependence*

The radiation efficiency can be influenced by the orientation of the antenna and the operating frequency. Experimental studies have shown that for vertical orientation, the radiation efficiency can be enhanced by 10 % to 23 % in the frequency range of 2 MHz to 8 MHz, compared to horizontal orientation, where the efficiency is limited to approximately 2 %.

By employing these techniques and optimizing the antenna design parameters, it is possible to improve the radiation efficiency of vehicular antennas for HF band operation with NVIS communication, enabling more efficient and reliable communication [25, 26].

5.1.5. Directivity

Directivity is a fundamental parameter in antenna theory, representing the ratio of the maximum radiation intensity to the average radiation intensity [25]. It is mathematically expressed as:

D = (Maximum radiation intensity) / (Average radiation intensity).

The range of directivity is given by $1 \leq D < \infty$, where $D = 1$ corresponds to an isotropic radiator, which has an omnidirectional radiation pattern with equal radiation intensity in all directions.

As the value of D increases, the radiation pattern becomes more directional, with the maximum radiation intensity concentrated in a specific direction.

The directivity of an antenna is closely related to its effective aperture (Ae), which is a measure of the antenna's ability to capture or radiate electromagnetic energy. The relationship between directivity and effective aperture is given by:

$$D = (4\pi Ae) / \lambda^2.$$

1. As the effective aperture increases, the directivity also increases, resulting in a more directional radiation pattern. The effective aperture depends on various factors, including the antenna's geometry, size, and the voltage induced across the antenna terminals. The induced voltage is proportional to the incident electric field and the length of the antenna.

For example, a half-wave dipole antenna exhibits a figure-eight radiation pattern, with maximum radiation intensity perpendicular to the antenna's axis [30]. In contrast, a monopole antenna, which is essentially a half-wave dipole with a ground plane, exhibits a unidirectional radiation pattern, with maximum radiation intensity in one direction.

2. As radius of conductor is increasing, Bandwidth became narrow. So, chances are to get unidirectional pattern with antenna with large radius [6].

5.2. Design of HF band vehicular antenna

By carefully designing the antenna's geometry and optimizing the effective aperture, it is possible to achieve the desired directivity and radiation pattern for specific applications, such as vehicular antennas in the HF band with NVIS communication. Here, the design of the inverted L antenna is shown below [2]:

If, $f = 30$ MHz, $\lambda = c/f = (3\cdot 10^8)/(30\cdot 10^6) = 10$ m.

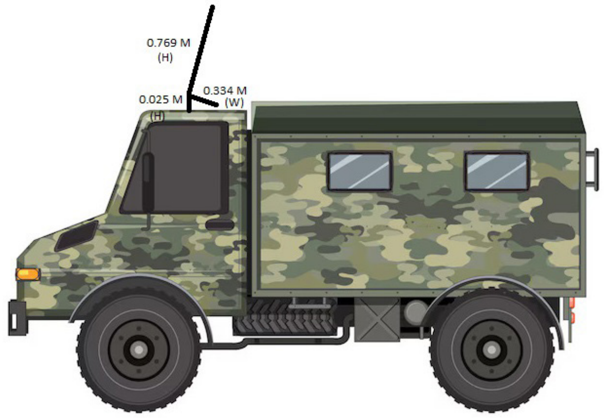


Figure 6 – Design of inverted *L* HF band antenna with NVIS (scale: 1 m = 1 cm)

Where 'm' stands for meters, '*L*' stands for Length, 'W' stands for Width, 'Height' stands for Height of Antenna.

NEC2, CST, HFSS etc are several simulation software available on which proposed antenna can be designed. Table 2 below shows comparison of Simulation Tools.

Table 2

Comparison of simulation tools

Simulation tool	Method based on	Observation
NEC2	MOM	• Computational time is less; • It is a free software; • 3D figures are not possible as such
HFSS	FEM	• Computational time is more; • 3D figures of all fields, pattern is possible; • Values of parameters are close to practical values
CST	FIT	• Computational time is more; • 3D figures of all fields, pattern is possible

Among these, HFSS is preferred. HFSS uses adaptive meshing, the Finite Element Method (FEM), and stunning graphics to provide unmatched performance and understanding for all of your 3D EM challenges. S-Parameters, Resonant Frequency, and Fields are among the parameters that may be calculated using HFSS.

Conclusion

This paper addresses the design challenges and limitations of vehicular antennas operating in the high-frequency (HF) band with Near Vertical Incidence Skywave (NVIS) communication for military applications. The primary objectives are to enhance critical performance parameters such as gain, radiation efficiency, and bandwidth, and achieve unidirectionality while integrating NVIS capabilities.

The proposed solutions include the incorporation of inductors, capacitors, and multiarming techniques to optimize antenna parameters. Material selection, such as the use of graphene with high conductivity, is also explored. Proper adjustment of the radiation angle and effective aperture optimization are emphasized to reduce the skip zone and achieve the desired directivity.

By implementing these design strategies, the research aims to develop a low-profile, efficient HF band vehicular antenna with improved gain (better than -20 dBi), radiation efficiency, and bandwidth, while enabling secure and reliable data and voice transmission through NVIS communication. The integration of NVIS capabilities further extends coverage in nearby regions, addressing the skip zone limitation. The proposed solutions address the existing limitations in vehicular antenna design for military applications, enabling secure and efficient communication in challenging environments. The research contributions pave the way for further advancements in antenna technology and have potential implications beyond military applications, benefiting various fields requiring reliable and secure communication systems.

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