Educational Note

UNDERSTANDING NVIS

Paul Denisowski | Version 1.1 | 07.2020

ROHDE&SCHWARZ

Make ideas real

Contents

1 Introduction

Near vertical incidence skywave (NVIS) is an HF propagation mode in which signals are transmitted towards, and returned from, the ionosphere almost vertically in order to provide local or regional coverage. NVIS is also often used in environments that are challenging for traditional HF propagation modes, such as in mountainous regions.

This educational note is divided into two sections. The first section provides a brief overview of HF and the more common HF propagation modes. NVIS can be considered a special case of skywave propagation, and thus emphasis is placed on ionospheric propagation, in particular the role of frequency and incidence angle. The second section discusses the technical principles underlying NVIS, the different types of antennas commonly used for NVIS operation, as well as the technical and operational aspects of NVIS.

2 HF Overview

2.1 About HF

HF stands for “high frequency” and refers to frequencies in the range of 3 MHz to 30 MHz, although in many cases the practical definition of HF can be extended down to approximately 1.5 MHz. These frequencies correspond to wavelengths in the range of approximately 10 to 100 meters. HF is most commonly associated with long range or global communications, and this capability sets HF apart from most other communications technologies. Broadcasters use HF to reach listeners worldwide and HF is also widely used for government and military applications, in part because HF does not require a fixed and potentially vulnerable “infrastructure” such as terrestrial cables or satellites. The ability to use HF in an ad hoc manner also makes it well suited for use in disaster relief and recovery, or in parts of the world that may be lacking a reliable communications infrastructure. Amateur radio operators around the world also frequently use and experiment with HF. HF is best known for its usefulness in reaching stations thousands of kilometers away, but HF can also be effectively used for local or regional communications within a range of several hundred kilometers.

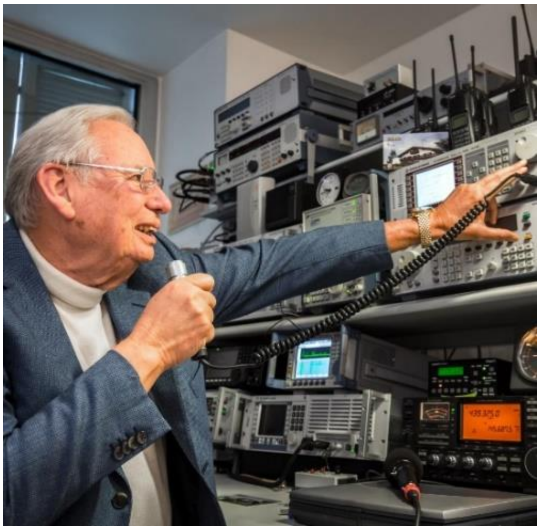

Figure 1 - Amateur radio operator Dr. Ulrich L. Rohde, DJ2LR / N1UL, operating on HF

2.2 HF Propagation Modes

One of the challenges in HF is choosing the optimum frequency for communicating with a given location at a given date and time and under given propagation conditions. The choice of frequency is strongly dependent on the propagation mode, i.e. the way in which HF signals travel between source and destination. There are three main HF propagation modes: line of sight, groundwave, and skywave.

2.2.1 Line of Sight

In line of sight or "direct wave" propagation, signals travel in a straight, unobstructed path between the transmitter and the receiver. Line of sight is the only HF propagation mode which is fairly constant – the ability to use line of sight to communicate with a given station doesn't vary substantially over periods of minutes, hours, days, months, years, etc. Furthermore, the range of frequencies that can be used for line of sight HF communication is fairly large. HF is, however, not often used for line of sight communications between ground-based stations. There are several reasons for this. Since HF wavelengths are long compared to VHF and UHF wavelengths, larger antennas are often required and the bandwidth available at HF frequencies is also somewhat limited. Furthermore, there tends to be much more noise at HF compared to higher frequencies, and this higher noise is even more problematic given that HF communications are usually carried out using AM or single-sideband. These modulation types are much more sensitive to noise than FM. Another potential disadvantage of line of sight propagation is that intervening objects between transmitter and receiver can significantly attenuate signals. Trying to use HF for line of sight communications in a jungle or from within a valley often does not yield acceptable results.

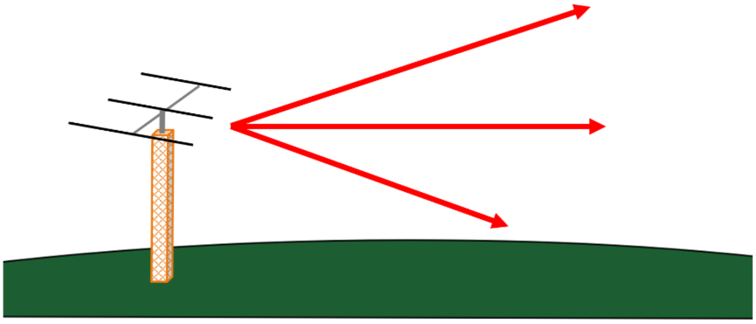

Figure 2 - Line of sight propagation

2.2.2 Groundwave

If line of sight between two stations does not exist, groundwave is a possible solution for short-range communication at HF. Groundwave, sometimes also called "surface wave," involves signals propagating along the surface of the Earth. Interaction between the lower part of the transmitted wavefront and the Earth's surface cause the wave to tilt forward, allowing the signal to follow the curvature of the Earth, sometimes well beyond line of sight. Groundwave propagation is, however, highly dependent on two different factors: the conductivity of the surface and the frequency of the transmitted signal. In general, higher surface conductivity gives better results in the form of greater distances that can be covered. Salt water has excellent conductivity, especially compared to dry or rocky land, so groundwave is a good choice for ship-to-ship or ship-to-shore communications.

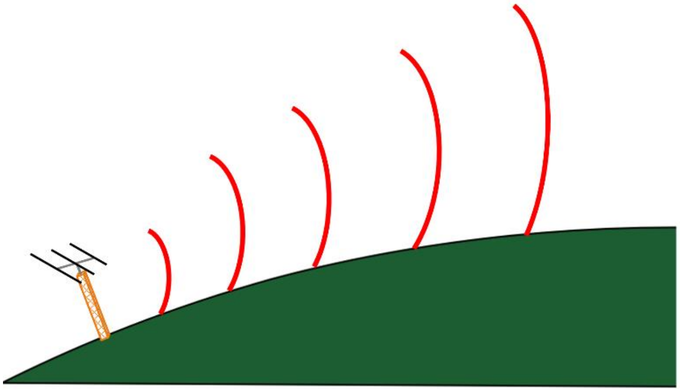

Figure 3 - Groundwave propagation

Groundwave works best for lower frequencies. For example, the theoretical range of 150 watt transmitter at 7 MHz is 35 kilometers over land, and close to 250 kilometers over the sea. At 30 MHz, however, the theoretical range falls to only 13 kilometers over land and just over 100 kilometers at sea.

2.2.3 Skywave

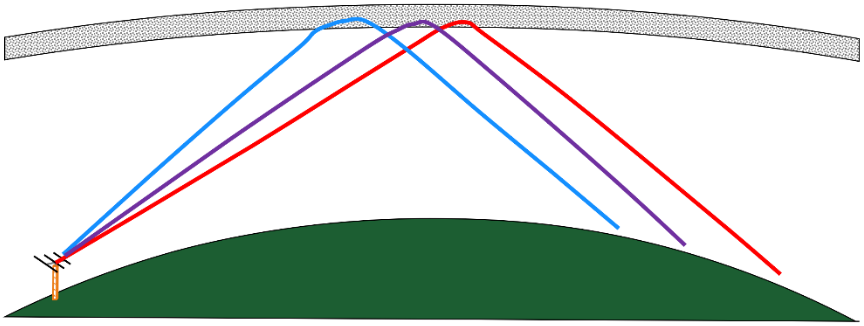

Figure 4 - Skywave propagation

The most well-known HF propagation mode – and the mode that is used in NVIS – is skywave. Skywave propagation enables beyond line of sight or even global communications, depending on propagation conditions. In skywave, layers of ionized particles in the upper atmosphere refract HF signals back towards earth, allowing communications over many thousands of kilometers. The distances that can be covered using a given frequency is primarily a function of two factors. The first is the state of these layers of ionized particles, collectively referred to as the ionosphere, and the second is the incidence angle.

2.3 The Ionosphere

2.3.1 About ionization

The ionosphere gets its name from the fact that this is the region where most atmospheric ionization occurs. When ultraviolet energy or radiation from the sun strikes gas atoms or molecules in the atmosphere, this energy can cause electrons to become detached. The result is a positive ion and, more importantly, a free electron. The Earth's magnetic field keeps these free electrons roughly in place. The level of ionization and the number of free electrons increases as the amount of sunlight striking a given part of the atmosphere increases. When a region of the atmosphere rotates away from the sun, i.e. at night, this ionization energy is removed and the ions recombine to form electrically neutral atoms. Note that recombination is a slower process than ionization – atmospheric ionization increases rapidly at dawn, but decreases less rapidly after dusk.

2.3.2 About the ionosphere

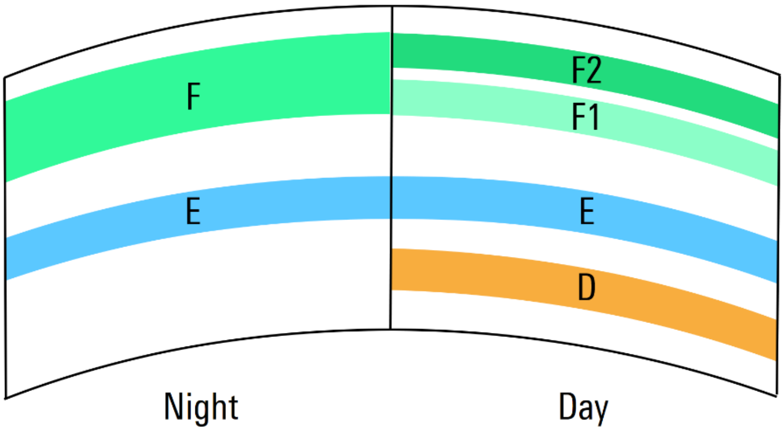

Figure 5 - Ionospheric layers

As mentioned earlier, the region of Earth's atmosphere that undergoes this ionization is collectively called the "ionosphere." The level or density of ionization in the ionosphere is different at different altitudes, and areas with ionization peaks are grouped into so-called "layers" or "regions." The layers that are important for HF skywave propagation are the D-layer, from 60 to 100 km; the E-layer, from 100 to 125 km; and the F-layer, or layers, from about 200 to 275 km. Note that these are only rough numbers – the "thickness" and "altitude" of ionospheric layers varies based on many factors such as the amount of solar radiation they receive. Each of these layers affects HF signals in different ways. It is important to remember that the ionosphere does not *reflect* signals but rather *refracts* signals. The different electron densities at different altitudes is responsible for ionospheric refraction of radio frequency signals.

2.3.3 D-layer

The D-layer only exists during daytime hours and disappears at night. Although the D-layer is ionized by solar radiation, the density of free electrons in the D-layer is too low to effectively refract HF signals and therefore the D-layer cannot be used for skywave communications. In fact, the D-layer inhibits HF skywave communications because it acts as an absorber of HF signals. The lower the frequency of a signal, the more that signal is attenuated by D-layer absorption. D-layer absorption also increases with increasing ionization, so absorption is usually highest at midday, when solar radiation is highest. Because of D-layer absorption, higher frequency HF skywave signals propagate better during the daytime, whereas lower frequency signals propagate better at night, after the D-layer has disappeared.

2.3.4 E-layer

The next highest layer, the E-layer, is the lowest layer of the ionosphere that has the ability to refract HF signals back towards the Earth. Compared to the other layers of the ionosphere, the E-layer is relatively thin, usually approximately 10 - 25 km. Like the D-layer, the E-layer is much more “dense” or ionized, during the day, but unlike the D-layer it does not completely disappear at night. However, aside from mostly short-range, daytime communications and a few other special cases, E-layer propagation is not responsible for the vast majority of HF skywave communications. It is however worth noting that at the higher VHF frequencies, E-layer propagation is very important and supports some rather exotic and less predictable propagation modes, such as sporadic-E, that enable long-distance VHF communication over thousands of kilometers.

2.3.5 F-layer

The F-layer is by far the most important ionospheric layer for HF skywave propagation. During daylight hours, the F-layer splits into two sub-layers: F1 and F2, which then merge back into a single layer again at night. Compared to the D and E layers, the height of the F-layer(s) changes considerably based on various factors such as time of day, season, and solar conditions The lower F1-layer primarily supports short- to medium-distance communications during daylight hours. The F2-layer, on the other hand, is present more or less around the clock. The F2-layer has the highest altitude and the highest ionization of all the layers and is therefore responsible for the vast majority of long-distance skywave communications at HF.

2.4 Frequency and Incidence Angle

2.4.1 MUF and LUF

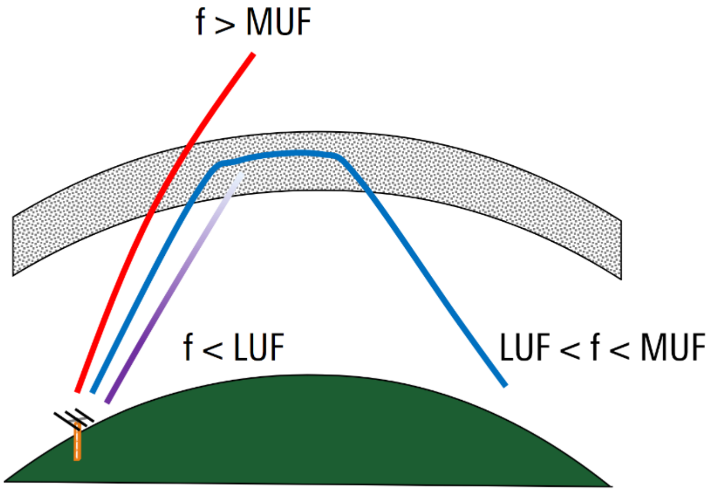

Figure 6 - MUF and LUF

The degree to which the different layers of the ionosphere refract and/or absorb radio frequency signals is partly a function of that signal's frequency. The general rule for HF skywave communications is to always use the highest possible frequency that will reach a given station or destination. This is called the **maximum usable frequency** (MUF). Signals whose frequencies are higher than the MUF will not be refracted by the ionosphere, but will instead penetrate the ionosphere and continue to propagate into space without being returned to Earth. Generally speaking, the MUF increases with increasing ionization. Another important frequency threshold is the **lowest usable frequency** (LUF). When the signal frequency is at or below the LUF, communication becomes difficult or impossible due to signal loss or attenuation. In HF skywave communications, frequencies should therefore be chosen such that they fall between the LUF and MUF, and this is true for both "traditional" HF skywave propagation as well as for NVIS. It should also be noted that there is a very important difference between MUF and LUF. Because the LUF is mostly determined by noise, using higher transmit powers, better antennas, etc. can improve or lower the LUF. MUF, on the other hand, is entirely a function of the ionosphere. Higher transmit power or a better antenna will not improve or increase the MUF.

2.4.2 Critical Frequency

The maximum usable frequency is usually estimated based on the **critical frequency**. The process for measuring the critical frequency is as follows: pulses at various frequencies are transmitted vertically by equipment called ionosondes. Depending on the frequency of the pulse, these pulses are returned by different layers of the ionosphere and the return time can be used to estimate the heights of different ionospheric layers. Once a certain frequency is reached, pulses are no longer returned by the ionosphere and instead continue on into space – this is the critical frequency. Critical frequency is a function of both the current ionization level as well as the measurement location: critical frequency is measured regularly at hundreds of locations around the world. Mathematically, the maximum usable frequency is the critical frequency divided the cosine of the angle of incidence: if a signal is transmitted vertically at 90°, MUF and critical frequency are the same. As a practical matter, the maximum usable frequency is usually estimated at 3 to 5 times the critical frequency for traditional skywave communications using a low incidence angle.

2.4.3 Incidence Angle

The **incidence** (or incident) **angle** is the angle at which a signal reaches the ionosphere, and incidence angle plays an important role in determining how far a skywave signal will propagate. The radiation or "takeoff" angle of an antenna is primarily a function of both the type of antenna and the location at which the antenna is installed. Higher placement of an antenna usually lowers the take-off / incidence angles and the lower the incidence angle, the greater the distance covered by skywave propagation.

A consequence of low incidence angles is the creation of **skip zones**. In these skip zones, HF signals cannot be received either via skywave or via groundwave propagation. One way to provide coverage within a skip zone is the use of higher incidence angle signals, since a very high incident angle causes signal to be returned to Earth closer to the transmitter.

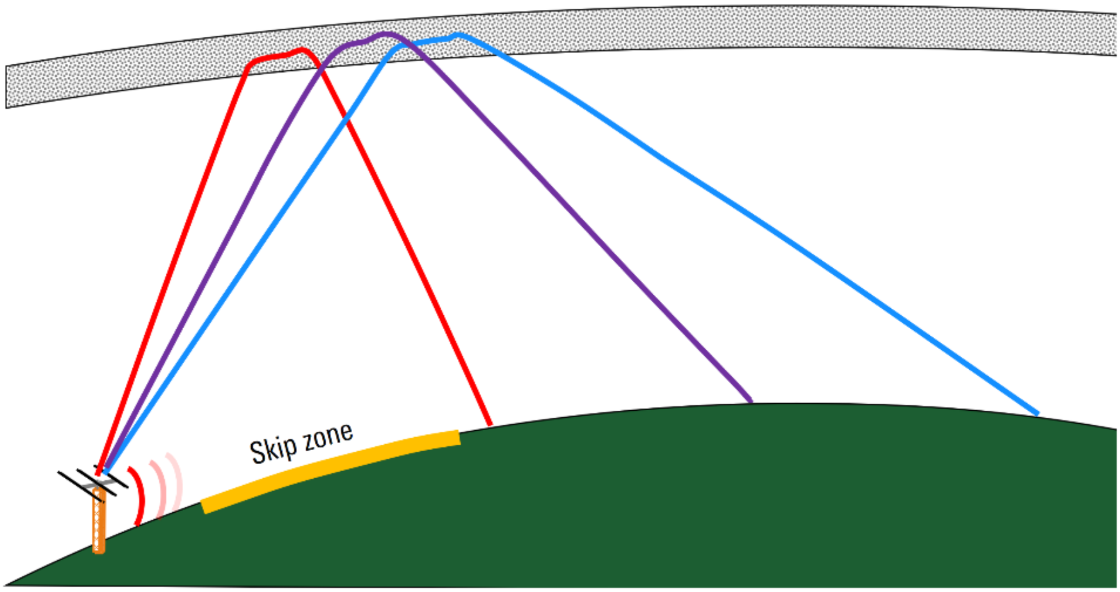

Figure 7 - Incidence angle and skip zone

3 NVIS Principles and Applications

3.1 NVIS Overview

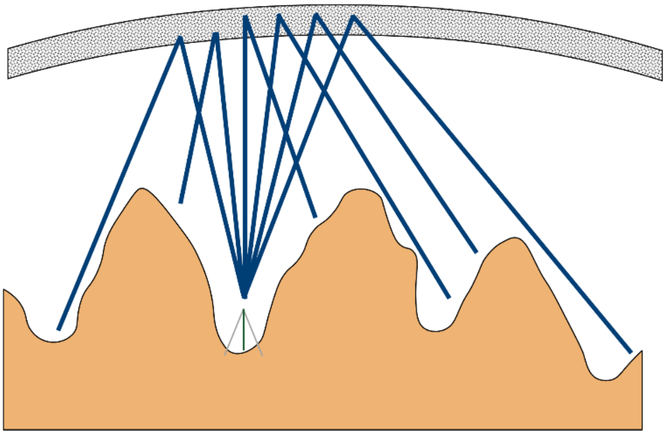

Figure 8 - Near vertical incidence skywave

As the name implies, **near vertical incidence skywave** (NVIS) is a special case of HF skywave propagation that enables both skip zone coverage as well as coverage in challenging terrain, where groundwave or low angle skywave signals might be blocked. NVIS is implemented using an antenna with a very high take-off angle, typically 75° or more, with transmission taking place on lower HF frequencies to ensure that signals are returned from ionosphere. The nearly-vertical take-off angle of these signals cause them to be returned to Earth relatively close to the transmitter. Coverage is often fairly uniform within a radius of up to several hundred kilometers from the transmitter. This local or regional coverage, combined with the easy setup of most NVIS antennas, makes NVIS very well-suited for applications that require ad hoc communications or communications in challenging terrain, such as military operations or disaster relief, where the existing communications infrastructure may have been damaged or destroyed.

3.1.1 NVIS Technical Advantages

NVIS has a number of purely technical advantages. The first of these is that NVIS is more resistant to fading than traditional skywave propagation and provides a more constant signal level. The near vertical incidence angle of NVIS means a shorter path through the D-layer and therefore less D-layer absorption. In addition, a shorter overall path length reduces the attenuation between transmitter and receiver. Attenuation of the signal due to terrain or obstructions is minimal because there is line of sight propagation between the transmitter and the ionosphere as well as between the ionosphere and the receiver(s). This line of sight propagation also helps to reduce fading due to multipath because a near-vertical take-off angle reduces the opportunities for the signal to be reflected from objects. The combination of these factors means that NVIS works well at relatively low transmit power levels, which is particularly important for portable or battery-powered operation in the field. The roughly omnidirectional coverage pattern created by a NVIS antenna makes antenna orientation or azimuth less critical in providing coverage to the desired locations, which in turn permits a great deal of flexibility in the setup and siting of NVIS antennas.

3.1.2 NVIS Operational Advantages

In addition to these purely technical benefits, NVIS also provides many operational benefits, particularly in a military environment. NVIS signals generally have a lower probability of intercept than conventional HF skywave signals. This lower probability of intercept comes from the fact that NVIS can operate at lower power levels and also from the vertically-focused radiation pattern. Both of these make it significantly more difficult to locate a NVIS station using direction finding (DF) techniques, particularly when the DF stations are ground-based: the energy from a NIVS antenna propagates primarily upwards and returns from the ionosphere with roughly equal strength over the coverage area. Furthermore, properly implemented NVIS antennas do not have a strong groundwave signal component and this makes it difficult to take a bearing on a NVIS station. Additionally, groundwave-based jamming is less effective when applied against NVIS stations. NVIS antenna patterns are designed to have very low or poor gain at traditional groundwave angles and therefore do not receive groundwave jamming signals as strongly as antennas with lower incidence angles. Another operational benefit of NVIS is that NVIS antennas are mounted comparatively low to the ground, making them discrete and difficult to notice. Being low to the ground also makes NVIS antennas easy to erect, and many can be set up by a single person. Finally, since the radiation pattern from a NVIS antenna is largely vertical, there is no need to “control the high ground” to make effective use of a NVIS antenna: obstructions in the horizontal plane, such as trees, mountains, buildings, etc. are much less important in NVIS compared to traditional skywave or line of sight propagation.

3.1.3 NVIS Disadvantages

There are, however, also some disadvantages when using NVIS. One of the most important of these is that NVIS only works at lower frequencies: the reasons for this are discussed below. The nature of NVIS antenna patterns and propagation limits the maximum range of NVIS to the low hundreds of kilometers, compared to the thousands of kilometers that can be achieved using traditional, low-incidence angle skywave propagation. Optimum results require the use of NVIS antennas on both the transmit and receive stations, although this requirement is somewhat looser for receive-only stations. An additional potential disadvantage of using NVIS is that both atmospheric and man-made noise levels tend to be higher at the lower frequencies that are used in NVIS-based communications

3.2 NVIS Frequencies

To make effective use of NVIS, the operator must choose frequencies that are low enough to be refracted by the F-layer of the ionosphere when arriving with a very high incidence angle. Signals with too high of a frequency will simply pass through the F-layer into space and will not be returned to Earth. In addition, NVIS requires the use of frequencies that are high enough to avoid excessive D-layer attenuation: recall that D-layer absorption is higher for lower frequency signals. In order to balance out these two somewhat conflicting requirements, NVIS operation uses frequencies in the range of approximately 2 to 10 MHz. Like all other skywave propagation, the maximum frequencies depend on the level of atmospheric ionization, and this in turn depends on factors such as sunspot number or solar flux index, the time of day, the season, and any “abnormal” solar events. For example, during solar minima, the maximum usable frequency for NVIS may only be 6 to 8 MHz. On average, however, NVIS frequencies range from 4 to 8 MHz during the day and from 2 to 4 MHz at night, but this can vary significantly. The specific frequency used for NVIS operation can be manually chosen by an operator based on experience and various ionospheric measurements or predictions, or the frequency can be automatically chosen using techniques such as automatic link establishment (ALE).

3.3 NVIS Antennas

3.3.1 Basic NVIS Antenna Principles

Most antennas intended for HF skywave communications are designed to have a low take-off or radiation angle. This lower take-off angle causes a lower angle of incidence with the ionosphere and hence longer distances due to lower refraction angles. In traditional, long-distance applications of HF skywave, an antenna that sends too much energy vertically is sometimes unflatteringly referred to as a “cloud warmer.” On the other hand, NVIS antennas are specifically designed and installed in order to have a high radiation angle, typically 75° or higher: the majority of power is “going up” instead of “going out,” so to speak. The most common method used to achieve this high take-off angle is by using an antenna that is located close to the ground.

3.3.2 NVIS antenna patterns

One of the best ways to understand the difference between traditional, low-incidence angle skywave antennas and NVIS antennas is to compare antenna patterns. Since NVIS can be implemented as a dipole, a useful comparison can be made between a “standard” HF dipole and a “NVIS” dipole. A “standard” HF dipole is usually mounted at a height that produces a relatively low elevation angle (Figure 9). The relationship between elevation angle and antenna height can be somewhat complex, but generally speaking, the higher a dipole is mounted above the ground, the lower its elevation or “take-off” angle. A lower elevation angle works well for long-distance HF skywave communications because greater distances can be achieved when the transmitted signal is incident to the ionosphere at lower angles. A dipole being used for NVIS is characterized by a much higher or more vertical elevation pattern. As will be discussed shortly, the primary method of creating this type of vertical radiation pattern is by moving the dipole closer to the ground. A higher elevation angle is necessary for NVIS, but clearly would not yield satisfactory results when used for traditional long-distance skywave communications.

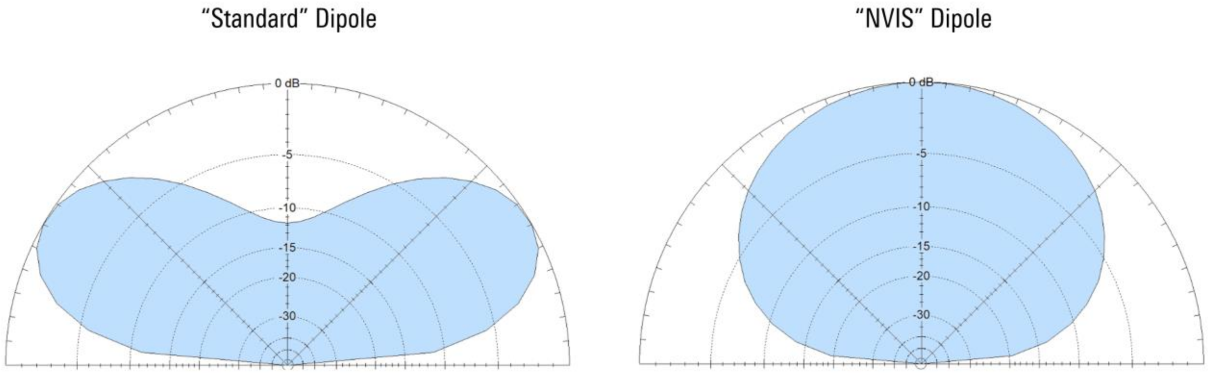

Figure 9 - Comparison of elevation patterns (traditional vs. NVIS)

Azimuth patterns (Figure 10) show the distribution of energy, or gain, in the horizontal plane around the antenna. A half-wave dipole suspended at “normal” heights above ground for traditional HF skywave communications has a directional pattern, with the majority of gain being broadside to the antenna. In a typical NVIS antenna, the azimuth pattern is roughly omnidirectional, meaning that the orientation of the NVIS antenna is less important: if the NVIS dipole were rotated 90°, the azimuth pattern would remain essentially the same. The azimuth pattern of the NVIS antenna shows that coverage is fairly uniform within the receive area – the NVIS antenna does not favor one azimuth or horizontal direction over another. This is especially important in typical military or disaster relief scenarios, where the location of the receiving station may not be known, where there are multiple receiving stations, or where the receiving station is “on the move." In these types of situations, a directional antenna pattern could be counterproductive since there may be no reliable way to know the direction in which the antennas should be pointed.

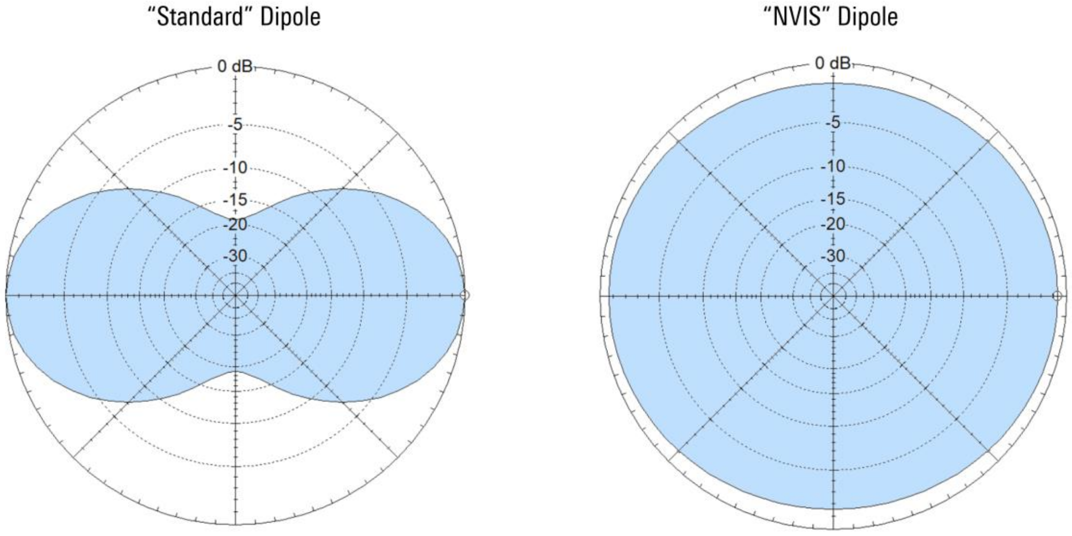

Figure 10 - Comparison of azimuth patterns (traditional vs. NVIS)

3.3.3 NVIS antenna types

NVIS describes a certain type of antenna, or more precisely, a certain radiation pattern or elevation angle produced by an antenna. There are however many different types of antennas that can be used or adapted to produce the high incidence angle NVIS antenna pattern. Given the most common applications of NVIS, so-called "field expedient" antennas; that is, antennas which are designed for portability and ease of setup, are often used as NVIS antennas. Some of the most frequently used types of NVIS are dipoles and inverted Vees, the latter being a variant of the standard horizontal dipole. Unbalanced wires are also used in NVIS, and there are a number of different types of vehicle mounted NVIS antennas. Other types of NVIS antennas are usually found in fixed-site applications where low-profile, portability, and/or ease of setup are less of a concern. These include conical spiral and vertical log periodic antennas, among others.

3.3.3.1 Dipole

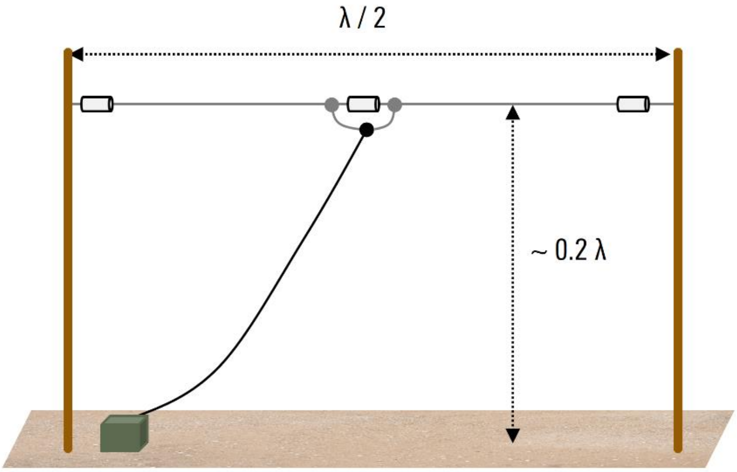

Figure 11 - NVIS dipole

The standard half-wavelength dipole used widely for low-angle HF skywave propagation can also be adapted for use in NVIS applications. A traditional skywave dipole is usually positioned roughly a half-wavelength above ground. In order to create a more vertical radiation angle, a NVIS dipole needs to be much lower, usually approximately 0.2 wavelengths above the ground. For example, if the operating frequency were 7 MHz, a NVIS dipole would be erected approximately 8 meters above the ground. Generally speaking, the lower the active element, the higher the radiation angle. To some extent, the optimum antenna height is also a function of ground conductivity: the higher the ground conductivity, the lower the optimal height. Because of this, the use of an optional reflector element has sometimes been recommended, for example, when the soil has very low conductivity such as sand or rock, or if the dipole is high above the ground. It does however remain unclear how much of an advantage this optional reflector provides in practice, and in most cases NVIS dipoles do not have a reflector installed under them. One final note regarding NVIS dipoles: if a single dipole is used for operation over a wide frequency range, an antenna tuning unit is often needed, but a set of dipoles, or a so-called “fan dipole” can also be used for NVIS applications to provide better matching over a wider range of frequencies.

3.3.3.2 Inverted Vee

An inverted Vee is a variant of the horizontal dipole, with the center of the dipole being supported by a vertical mast and the ends being close to or near the ground. A very common implementation of the inverted Vee in NVIS uses two dipoles, often positioned at roughly right angles to each other. This arrangement is sometimes referred to as a “turnstile” antenna. Using a pair of dipoles helps to overcome polarization-related fading. One of the main advantages of an inverted Vee over a standard horizontal dipole is that this type of antenna is easy to erect: it has only one central support and therefore can be raised by a single person. When using an inverted Vee for NVIS, the apex or peak of the mast should however still be kept low, usually only slightly higher than the height of a horizontal dipole. A lower height mast also ensures that the apex angle remains low, which is important for obtaining the desired vertical radiation pattern.

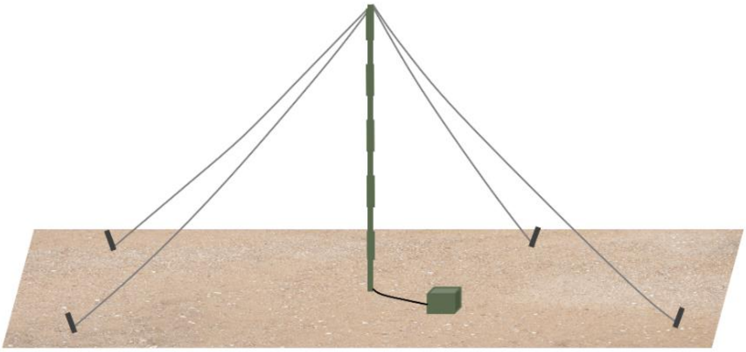

Figure 12 - Inverted Vee (turnstile configuration)

3.3.3.3 Unbalanced Wire

Dipoles are balanced antennas, but unbalanced antennas can also be used for NVIS. An inverted L is one example of an unbalanced NVIS antenna. The name “inverted L” refers to the shape of this antenna. Inverted L wire antennas are most commonly created by connecting a horizontal flattop to a vertical download. The antenna then works against ground or against a counterpoise if necessary. Like most other unbalanced antennas, an inverted L radiates along its entire length if the radio is connected to the end of the wire. Inverted L’s are also a popular choice for vehicle-mounted NVIS antennas.

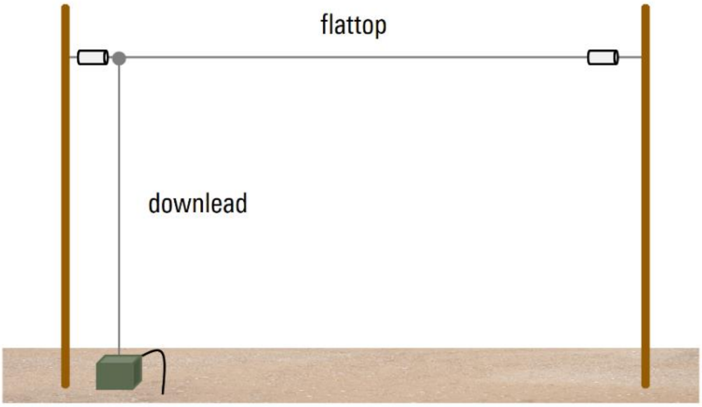

Figure 13 - Unbalanced wire (inverted L)

3.3.4 Mobile NVIS antennas

NVIS antennas can and often are deployed on vehicles. Loops are a popular choice for vehicle-mounted NVIS antennas because they allow the use of NVIS even when the vehicle is in motion. The standard vertical whip antenna found on many vehicles is a poor choice for NVIS due to the nature of its radiation pattern, but this type of antenna can often be bent or tied into a horizontal position for use as a NVIS antenna. In this configuration, the best performance is usually achieved by tying the antenna backwards, i.e. away from the vehicle. Bending the mast backwards has the advantage of reducing out of phase currents generated in the bodywork of the vehicle, but this also usually forces the vehicle to be stationary. Alternatively, the whip can be tied or fastened in the forward position, i.e. over the vehicle. This configuration allows the antenna to be used in motion, although at the cost of lowered efficiency and a less optimal radiation pattern. Generally speaking, a “proper” dedicated loop antenna is a better choice than an improvised loop made by bending a whip antenna in either direction.

Figure 14 - Vehicle mounted loop antenna

Another common NVIS antenna variant used in mobile applications (and particularly in airborne applications) is the “towel bar.” Towel bar antennas have the advantage of being low-profile and sturdy. A double towel bar arrangement is sometimes used to increase the effective size of the antenna and thereby increase the antenna’s bandwidth performance. Electrically, towel-bar antennas can be implemented to operate as dipole, loop, or inverted-L type antennas.

Figure 15 - Towel bar style antenna

4 Conclusion

NVIS is a special case of HF skywave propagation and uses antennas intended to produce very high take-off angles, typically 75° or higher. Unlike traditional low-angle skywave signals, the signals from a NVIS antenna are returned from the ionosphere almost vertically, and thus NVIS can provide local or regional coverage as well as coverage in challenging environments such as mountainous or jungle regions.

The omnidirectional coverage typically provided by NVIS makes antenna siting and orientation less critical compared to traditional HF skywave antennas. This flexibility facilitates communication with stations whose locations are not well known and also makes NVIS well-suited for use with temporary or field-expedient antennas. From an operational standpoint, using NVIS decreases probability of intercept, complicates ground-based direction finding by an adversary, and provides greater immunity to groundwave jamming.

The main challenge when using NVIS is that it only works well at lower HF frequencies, typically in the range of 2 to 10 MHz, with the maximum frequency being primarily a function of time of day and current solar conditions. NVIS is an antenna-based technology but can be implemented using a variety of different antennas. One of the more commonly encountered implementations of NVIS involves one or more dipoles mounted close to the ground, either horizontally or in an inverted-Vee configuration. Unbalanced antennas such as inverted Ls can also be used, and various types of loop antennas are often found in vehicle-mounted or mobile applications.

The ability of traditional, low incident skywave propagation to provide long-distance or global coverage is one of reasons for renewed interest in HF as a supplemental or backup communications system. NVIS complements traditional HF skywave by providing robust, reliable local communications under a wide variety of challenging conditions and thus is a key component in the recent "rebirth" of HF.

Rohde & Schwarz

The Rohde & Schwarz electronics group offers innovative solutions in the following business fields: test and measurement, broadcast and media, secure communications, cybersecurity, monitoring and network testing. Founded more than 80 years ago, the independent company which is headquartered in Munich, Germany, has an extensive sales and service network with locations in more than 70 countries.

www.rohde-schwarz.com

Certified Quality Management
ISO 9001

Rohde & Schwarz training

www.training.rohde-schwarz.com

Rohde & Schwarz customer support

www.rohde-schwarz.com/support

PAD-T-M: 3572.7186.00/01.00/EN

R&S® is a registered trademark of Rohde & Schwarz GmbH & Co. KG
Trade names are trademarks of the owners.

| Version 1.1 | 07.2020
Educational Note | Understanding NVIS

Data without tolerance limits is not binding | Subject to change
© 2020 Rohde & Schwarz GmbH & Co. KG | 81671 Munich, Germany
www.rohde-schwarz.com