Near Vertical Incidence Skywave (NVIS) Propagation and Antennas

Al Penney
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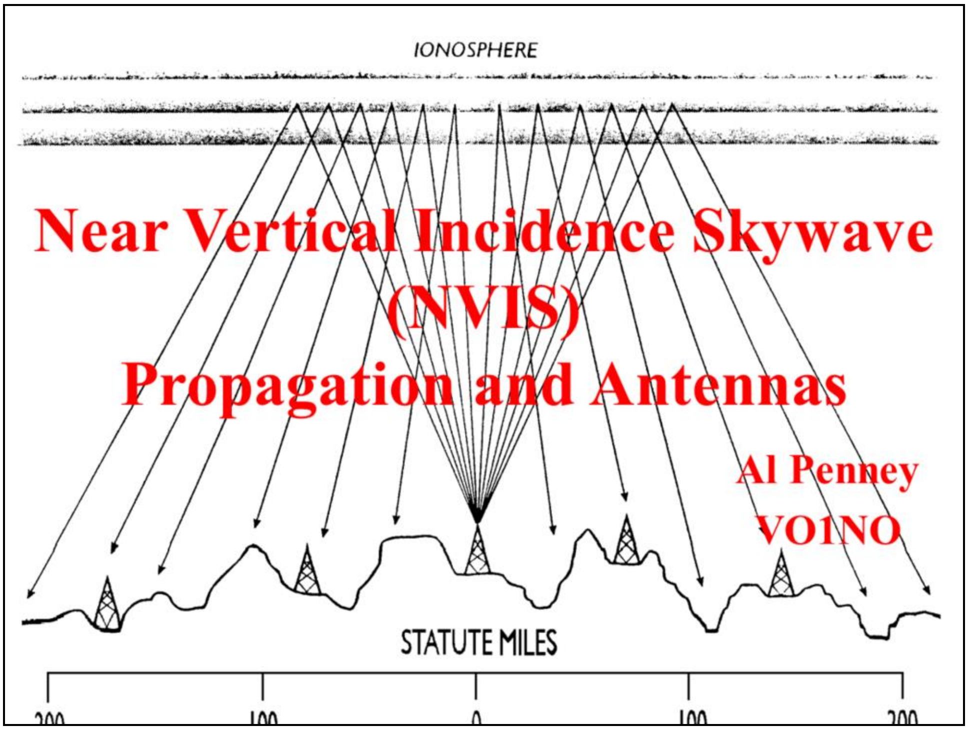

NVIS

- **Near Vertical Incidence Skywave**
- Skywave propagation 0 – 650 km.
- Signals travel **vertically or near vertically** before being refracted back to Earth.
- Used on 160, 80, 60 and 40M bands.
- Suitable for emergency communications, regional communications and mountainous regions.

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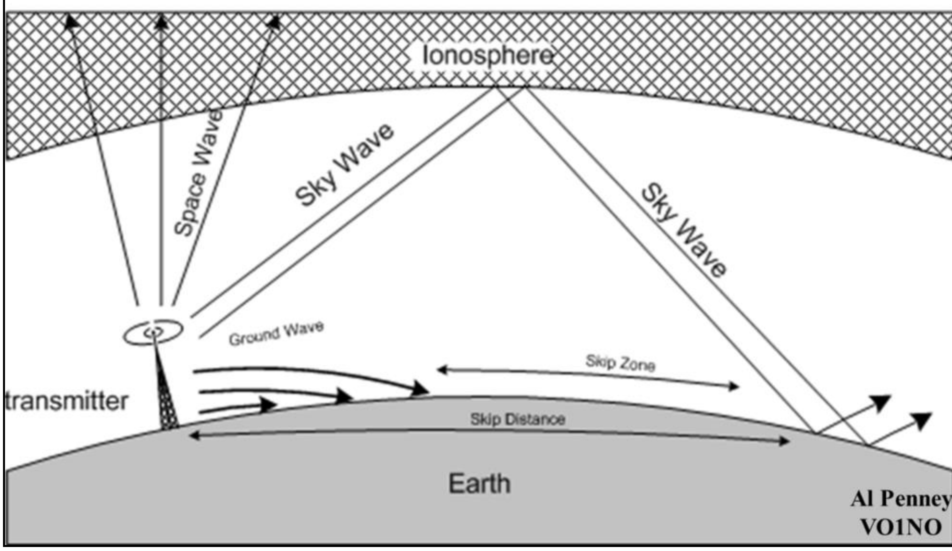
Near vertical incidence skywave, or **NVIS**, is a skywave radio-wave propagation path that provides usable signals in the distances range — usually 0–650 km (0–400 miles). It is used for military and paramilitary communications, broadcasting, especially in the tropics, and by radio amateurs for nearby contacts circumventing line-of-sight barriers. The radio waves travel near-vertically upwards into the ionosphere, where they are refracted back down and can be received within a circular region up to 650 km (400 miles) from the transmitter.

- If the frequency is too high (that is, above the critical frequency of the ionospheric F layer), refraction fails to occur and if it is too low, absorption in the ionospheric D layer may reduce the signal strength.

- There is no fundamental difference between NVIS and conventional skywave propagation; the practical distinction arises solely from different desirable radiation patterns of the antennas (near vertical for NVIS, near horizontal for conventional long-range skywave propagation).

“Regular” Propagation



Because the skywave can be refracted back to Earth a long distance from the transmit antenna, the may be a region between the extent of the ground wave from the antenna to the point where the skywave is first refracted back to Earth where there is no signal.

Skip Zone – The **area** between the furthest reach of the Ground Wave and the point where the Sky Wave is first refracted back to Earth. **No signal** is heard in the Skip Zone.

Skip Distance – The **minimum distance** reached by a signal **after refraction** or reflection by the Ionosphere.

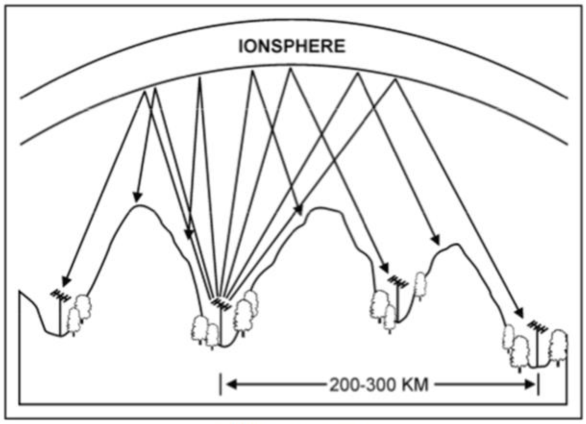
Ground wave propagation results from radio waves following the surface of the earth. In this mode, they are guided waves and, depending on the earth under them, can travel dozens of miles to reach their receiver. This is the usual mode by which we hear AM broadcast stations. While this mode exists at VHF and above it is most common at medium frequencies (300 kHz to 3 MHz) and high frequencies (3 MHz to 30 MHz).

Skywave propagation involves reflecting signals off the ionosphere. It is in this mode that medium and high frequency radio exhibits its unique and special qualities. This reflection technique allows us to leap tall mountains with a single bound. It enables us to talk with stations on the other side of the earth. And, if used correctly, enables us to provide continuous and dependable coverage of areas of operation that span several hundred miles. It is this capability, and the need for it in tactical operations of regional agencies as well as military corps and smaller units, that makes it important to understand NVIS communications techniques.

Ground propagation works because lower-frequency waves are more strongly diffracted around obstacles due to their long wavelengths, allowing them to follow the Earth's curvature. **Ground waves propagate in vertical polarization**, with their magnetic field horizontal and electric field (close to) vertical.

Conductivity of the surface affects the propagation of ground waves, with more conductive surfaces such as sea water providing better propagation.[1] Increasing the conductivity in a surface results in less dissipation.[2] The refractive indices are subject to spatial and temporal changes. Since the ground is not a perfect electrical conductor, ground waves are attenuated as they follow the earth's surface. The wavefronts initially are vertical, but the ground, acting as a lossy dielectric, causes the wave to tilt forward as it travels. This directs some of the energy into the earth where it is dissipated,[3] **so that the signal decreases exponentially.**

NVIS Propagation



NVIS propagation

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Why not use Groundwave? Efficient groundwave propagation requires vertical polarized antennas, and good surface conductivity. Vertical antennas may be difficult to erect in

emergencies, or for tactical reasons, and mountains are generally not very conductive.

(Cover this in later slide) The most reliable frequencies for NVIS communications are between 1.8 MHz and 8 MHz. Above 8 MHz, the probability of success begins to decrease, dropping to near zero at 30 MHz. Usable frequencies are dictated by local ionospheric conditions, which have a strong systematic dependence on geographical location. Common bands used in amateur radio at mid-latitudes are 3.5 MHz at night and 7 MHz during daylight, with experimental use of 5 MHz (60 meters) frequencies. During winter nights at the bottom of the sunspot cycle, the 1.8 MHz band may be required. Broadcasting uses the tropical broadcast bands between 2.3 and 5.06 MHz, and the international broadcast bands between 3.9 and 6.2 MHz. Military NVIS communications mostly take place on 2–4 MHz at night and on 5–7 MHz during daylight.

Optimum NVIS frequencies tend to be higher towards the tropics and lower towards the arctic regions. They are also higher during high sunspot activity years. The usable frequencies change from day to night, because sunlight causes the lowest layer of the ionosphere, called the D layer, to increase, causing attenuation of low frequencies during the day while the maximum usable frequency (MUF) which is the critical frequency of the F layer rises with greater sunlight. Real time maps of the critical frequency are available. **Use of a frequency about 15% below the critical frequency should provide reliable NVIS service.** This is sometimes referred to as the optimum working frequency or FOT.

NVIS is most useful in mountainous areas where line-of-sight propagation is ineffective, or when the communication distance is beyond the 50 mile (80 km) range of groundwave (or the terrain is so rugged and barren that groundwave is not effective), and less than the 300–1500 mile (500–2500 km) range of lower-angle sky-wave propagation. Another interesting aspect of NVIS communication is that direction finding of the sender is more difficult than for ground-wave communication (i.e. VHF or UHF). For broadcasters, NVIS allows coverage of an entire medium-sized country at much lower cost than with VHF (FM), and daytime coverage, similar to mediumwave (AM broadcast) nighttime coverage at lower cost and often with less interference.

Critical Frequency

- The **highest frequency** that, if directed **vertically upward**, will be **refracted back** to Earth by an ionized layer.
- Also called the **Penetrating Frequency**.
- Gives an indication of the state of the ionosphere and resulting propagation.

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The critical frequency is an important figure that gives an indication of the state of the ionosphere and the resulting HF propagation. It is obtained by sending a signal pulse directly upwards. This is reflected back and can be received by a receiver on the same site as the transmitter. The pulse may be reflected back to earth, and the time measured to give an indication of the height of the layer. As the frequency is increased a point is reached where the signal will pass right through the layer, and on to the next one, or into outer space. The frequency at which this occurs is called the critical frequency.

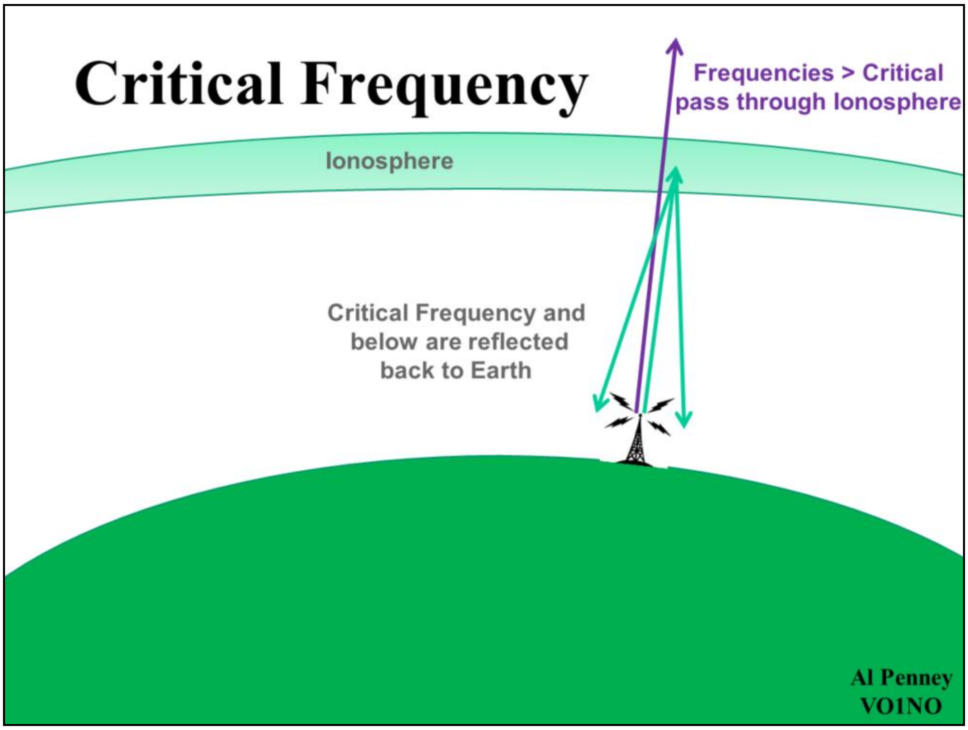
The equipment used to measure the critical frequency is called an ionosonde. In many respects it resembles a small radar set, but for the HF bands. Using these sets a plot of the reflections against frequency can be generated. This will give an indication of the state of the ionosphere for that area of the world

In radio propagation by way of the ionosphere, the limiting frequency at or below which a wave component is reflected by, and above which it penetrates through, an ionospheric layer.

Critical Frequency changes with time of day, atmospheric conditions and

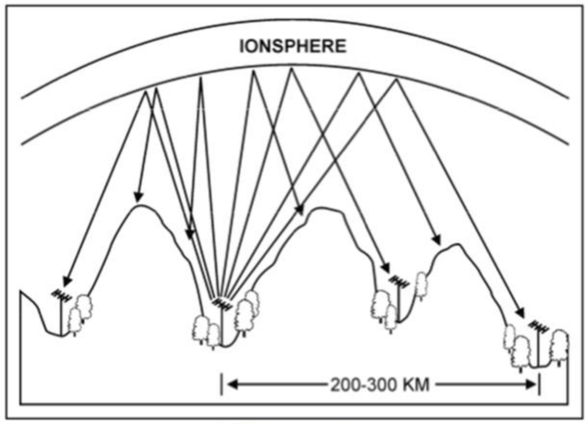
angle of fire of the radio waves by antenna.

The existence of the critical frequency is the result of electron limitation, *i.e.,* the inadequacy of the existing number of free electrons to support reflection at higher frequencies.



Frequencies that are too low are absorbed by the D Layer!

NVIS Propagation



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NVIS Frequency

- Generally in the range **1.8 – 8 MHz.**
- Must be **less** than **Critical Frequency** of **F2 layer**.
- Main criteria is local ionospheric conditions:
  - D-layer absorption attenuates low frequencies during day;
  - F2 Critical Frequency higher during day, lower at night;
  - Optimum frequencies higher in tropics, lower in Arctic; and
  - Optimum frequencies lower during solar minimum.
- Will usually need daytime and nighttime frequencies.
- Optimum frequency generally **10-15% below F2 Critical Frequency (foF2).**

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The selection of an appropiate working frequency is essential for a successful operation in NVIS. As a general rule, **we will choose a frequency 10% to 15% below the ionosphere's F2 layer critical frequency (foF2) at a given time**.

It is of particular importance not to confuse the foF2 with the MUF. The critical frequency foF2 is the maximum frequency that a radio wave can have in order to be reflected in the F2 layer when arriving at this layer with an angle of incidence of 90 degrees (perpendicular). In the MUF, angles of incidence different of 90 degrees are considered, which practically means that a different MUF will exist for each distance of a HF radio link.

The most reliable frequencies for NVIS communications are between 1.8 MHz and 8 MHz.

-Above 8 MHz, the probability of success begins to decrease, dropping to near zero at 30 MHz.

-Usable frequencies are dictated by local ionospheric conditions, which have a strong systematic dependence on geographical location.

-Common bands used in amateur radio at mid-latitudes are 3.5 MHz at night and 7 MHz during daylight, with experimental use of 5 MHz

(60 meters) frequencies. During winter nights at the bottom of the sunspot cycle, the 1.8 MHz band may be required.

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Our goal now is to get foF2 forecasts or, much better, real time measurements of the foF2 made with an ionosonde nearby our transmitter station at a close time. Let's not forget that the foF2 has significant changes over the day and also that it will be different depending on the transmitter location.

In order to get this data, we can check the web site of the Mass Lowel University Center for Atmospheric Research (Massachussetts, USA), where there is a record of foF2 values (among other parameters) measured by ionosondes all around the world.

http://ulcar.uml.edu/stationmap.html

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Frequency selection: In skywave propagation, there is a critical frequency (*fO*) above which radiated energy generally will not be reflected by the ionosphere but will pass through it. This frequency is related approximately(by a constant *k* slightly greater than unity which depends primarily on path length) to the angle of incidence (θ) and the classical maximum usable frequency (MUF) by the equation: $\mathrm{MUF} = kk \cdot ffOO \cdot \sec \theta\theta$. This means that the useful frequency range varies in accordance with the path length: the shorter the path the lower the MUF and smaller the frequency range. The lowest useful frequency (LUF) is determined primarily by the effective radiated power and the noise and interference at the receiver. Practically speaking, this limits the NVIS mode of operation to the 2-4 MHz range at night and between 4-8 MHz during the day. These nominal limits will vary with the 11- year sunspot cycle and they will be smaller during sunspot minimums

F2 Critical Frequency foF2

- Measured with Ionosondes or Chirpsounders:
  - Upward pointing radar sweeps through 1.6 – 12 MHz;
  - Echos indicate height of ionosphere reflecting layers;
  - Results displayed on an Ionogram.
- Measurements taken throughout world:

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An **ionosonde**, or **chirpsounder**, is a special radar for the examination of the ionosphere. The basic ionosonde technology was invented in 1925 by Gregory Breit and Merle A. Tuve [1] and further developed in the late 1920s by a number of prominent physicists, including Edward Victor Appleton. The term *ionosphere* and hence, the etymology of its derivatives, was proposed by Robert Watson-Watt.

An ionosonde consists of:

•A high frequency (HF) radio transmitter, automatically tunable over a wide range. Typically the frequency coverage is 0.5–23 MHz or 1–40 MHz, though normally sweeps are confined to approximately 1.6–12 MHz.

•A tracking HF receiver which can automatically track the frequency of the transmitter.

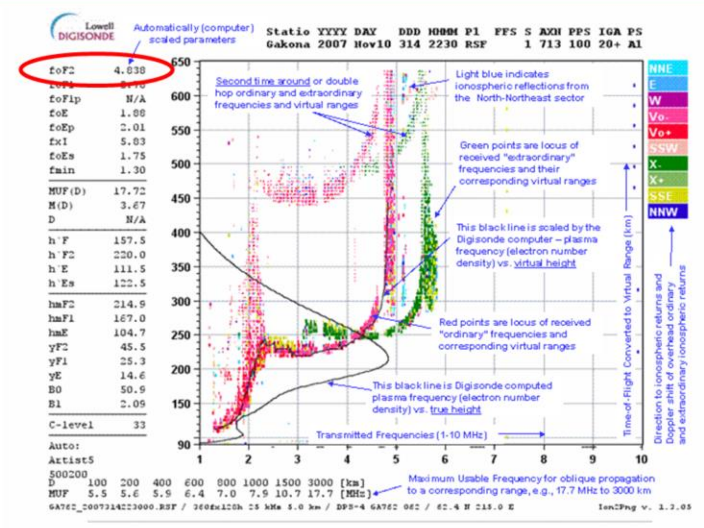
•An antenna with a suitable radiation pattern, which transmits well vertically upwards and is efficient over the whole frequency range used.

•Digital control and data analysis circuits.

The transmitter sweeps all or part of the HF frequency range, transmitting short pulses. These pulses are reflected at various layers of the ionosphere, at heights of 100–400 km, and their echos are received by the receiver and analyzed by the control system. The result is displayed in the form of an ionogram, a graph of reflection height (actually time between transmission and reception of pulse) versus carrier frequency.

An ionosonde is used for finding the optimum operation frequencies for broadcasts or two-way communications in the high frequency range.

Ionogram – Low SFI



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•Digisonde ionogram presents signals reflected from the ionosphere in the frequency vs travel time frame, with signal strength indicated by the pixel intensity, and wave polarization, angle of arrival, and Doppler frequency indicated by colors

•Individual reflected signals (echoes) observed on each sounding frequency form traces in the ionogram image

•Red (green) colors indicate vertical echoes with O-polarization (X-polarization)

•ARTIST software scales the ionogram and calculates the vertical Electron Density Profile (EDP) in real time

•Thin black lines show the ARTIST-identified O-traces

•The black line with uncertainty bars shows the calculated bottomside EDP

•Extraction and interpretation of the signal traces in ionogram images is an intelligent, machine-hard problem of feature recognition

Extraordinary Frequency - As a wave approaches the reflection point, its group velocity approaches zero and this increases the time-of-flight of the signal. Eventually, a frequency is reached that enables the wave to penetrate the layer without being reflected. For ordinary mode waves, this occurs when the transmitted frequency just exceeds the peak plasma frequency of the layer. In the case of the extraordinary wave, the magnetic field has an additional effect, and reflection occurs at a frequency that is higher than the ordinary wave by half the electron gyrofrequency.

In order to gain a view of the state of the ionosphere for various forms of radio communication, a test instrument known as an ionosonde is used.

The test instrument is sometimes also known as a vertical incidence sounder, VIS, and this name gives an indication of the operation of the ionosonde.

Ionosondes, and the ionograms they produce are essential test instruments used for investigating the state of the ionosphere. The outputs they produce are able to give an indication of the state of the ionosphere above them that can be used to create a picture of what the ionospheric conditions are like at that moment.

By detecting the state of the ionosphere using an ionosonde it is possible to build up a picture of the actual state of the ionosphere at that moment and also at that point on the globe. Using a network of these test instruments around the globe a more accurate picture can be built up and this data can be used to determine the optimum frequencies for HF broadcasting and radio communication links, both short range and long distance radio communication.

The concept of the ionosonde is that it is a form of test instrument that transmits pulses of RF power vertically upwards. It then receives the signal that is reflected and this shows many details about the ionosphere above it.

The signal is directed upwards towards the ionosphere. The signal rises and at some point it is possible that it is reflected back to Earth and received by a receiving antenna and system.

The signal is normally pulsed, like that of a conventional radar, and using the time delay for the returned signal, it is possible to determine the height of reflection.

Accordingly, it can be seen that the ionosonde is effectively a specialised form of pulsed radar that is used to detect the ionisation in the ionosphere.

The plot of the ionosonde output is called an ionograph and in early days this would have been printed out on paper, but modern systems will obviously use computer technology, storing the data for processing and display as required.

The signal from the ionosonde starts at a low frequency and is stepped up in frequency. Initially the signal is reflected back by the ionosphere, but as the frequency is increased it penetrates deeper into the relevant region and eventually passes on to the next ionised region where the same process occurs as the frequency is swept upwards. Eventually a point is reached where the signal passes though all the regions of the ionosphere and it is not reflected.

There is a time delay between when the signal is transmitted and the reflected signal is received. Knowing the speed that the signals travel, it is possible to convert this into a distance or height figure.

There is a variety of instruments that have been used over the years from different manufacturers and with different specifications but in essence they all provide the same function.

There have been many developments in ionosonde technology. Analogue systems were used up until the 1970s. These systems all swept through the relevant parts of the spectrum, normally from about 1 MHz up to between 15 and 25 MHz.

They generally used a relatively high power level, often up to 25 kW. Sweeps could take anywhere between about 30 seconds and 2 minutes which gave them the ability to look at relatively short term variations in the ionosphere.

Since the 1970s digital systems have been used. These provide essentially the same as the analogue ones, but provide considerably more facilities and they are able to manipulate the data far more easily as they use computing and digital signal processing technology.

What is an Ionogram

An ionogram is the form of plot that is produced by an ionosonde. It is essentially a plot of the altitude against frequency.

The vertical axis shows the height and the horizontal axis shows the frequency.

From the ionogram it is possible to see the critical frequencies for each of the ionospheric regions or layers. These are labelled as f_0 for each layer or region. In other words f_0 E is the critical frequency for the E region, etc.

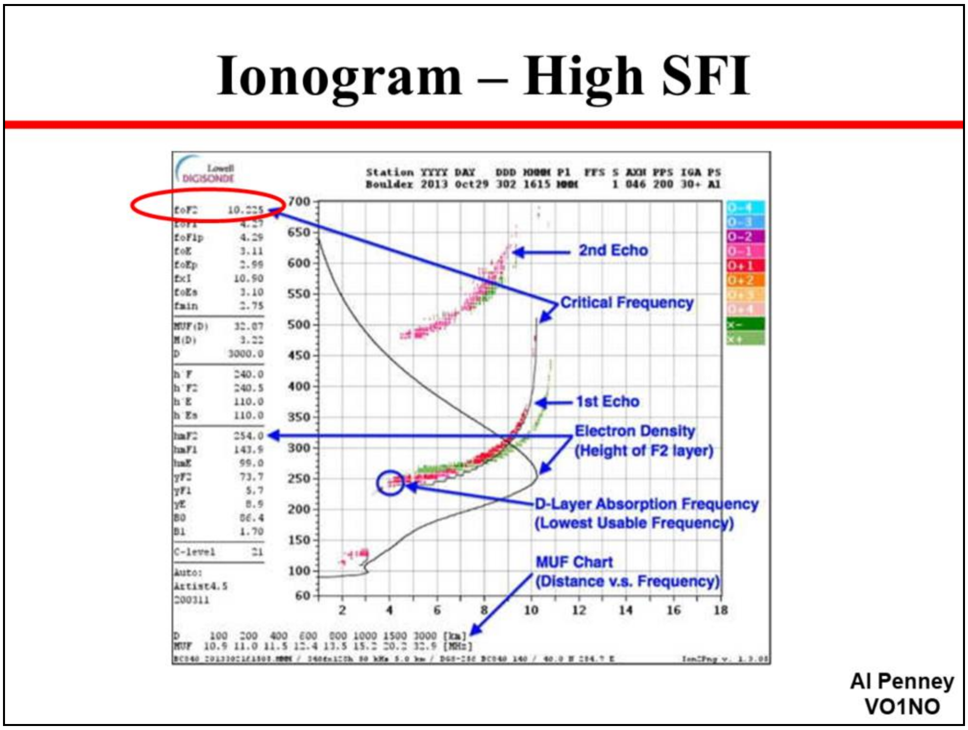
From the diagram, it can be seen that the signal is sent upwards and initially it is absorbed by the D layer and no reflection is seen.

As the signal moves up in frequency, it starts to be reflected back to the ground by the E region and the delay in receiving the pulse enables the approximate height to be determined.

As the frequency increases, the height of the reflection increases as the signal penetrates further into the E region. Ultimately the rate at which the signal penetrates the region for a given increase in frequency increases as the signal reaches the point at which it passes through the region. The actual frequency at which it passes through the E region is called the critical frequency, f_0 E.

Above f_0 E, the signal reaches the F_1 region (assuming the F region has split into two) and the process repeats. Again the same process repeats for the F_2, until the signal passes through all the different regions and travels on into outer space.

In reality the actual ionograms are less distinct than the diagrammatic ones, but the same basic patters can be made out.



The Critical Frequency, the highest frequency at which NVIS propagation can be used, is depicted as the foF2 frequency on the chart at the left of the graph and as the upper frequency limit of the first echo sounding curve.

The D-Layer absorption frequency, or Lowest Usable Frequency (LUF), is shown as the lower frequency limit of the first echo sounding curve.

The MUF chart at the bottom shows distances, in kilometers, versus the maximum usable frequency appropriate for the distance. Note that a conversion factor must be applied to determine the MUF for distances in miles (i.e. distance in kilometers X 0.62137119 = distance in miles).

Optimum NVIS Frequency

- On earlier page, foF2 = 4.838 MHz.
- Optimum NVIS frequency is foF2 – 10 to 15%:
  4.838 – 10% = 4.354 MHz
  4.838 – 15% = 4.112 MHz
- Therefore, Optimum NVIS frequency range at that location and time is 4.112 to 4.354 MHz.
- Amateurs can use 80M band, Military can select a frequency closest to that range, but always **below** Critical Frequency foF2.
- Remember – you may need **day/night** frequencies.

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An **ionogram** is a display of the data produced by an ionosonde. It is a graph of the virtual height of the ionosphere plotted against frequency. Ionograms are often converted into electron density profiles. Data from ionograms may be used to measure changes in the Earth's ionosphere due to space weather events.

Chirp transmitter

A chirp transmitter is a shortwave radio transmitter that sweeps the HF radio spectrum on a regular schedule. If one is monitoring a specific frequency, then a *chirp* is heard (in CW or SSB mode) when the signal passes through. In addition to their use in probing ionospheric properties, these transmitters are also used for over-the-horizon radar systems.

Ionosonde Data

- Canadian data available at (account required):
  - http://chain.physics.unb.ca/chain/pages/rules
- Other data at Global Ionosphere Radio Observatory:
  - http://giro.uml.edu/ionogram-data.html
  - Select closest location:
    https://ulcar.uml.edu/stationlist.html
    http://giro.uml.edu/IonogramMovies/
  - One Canadian location – Argentia
  - Millstone Hill, Massachussetts may be closest for Ontario

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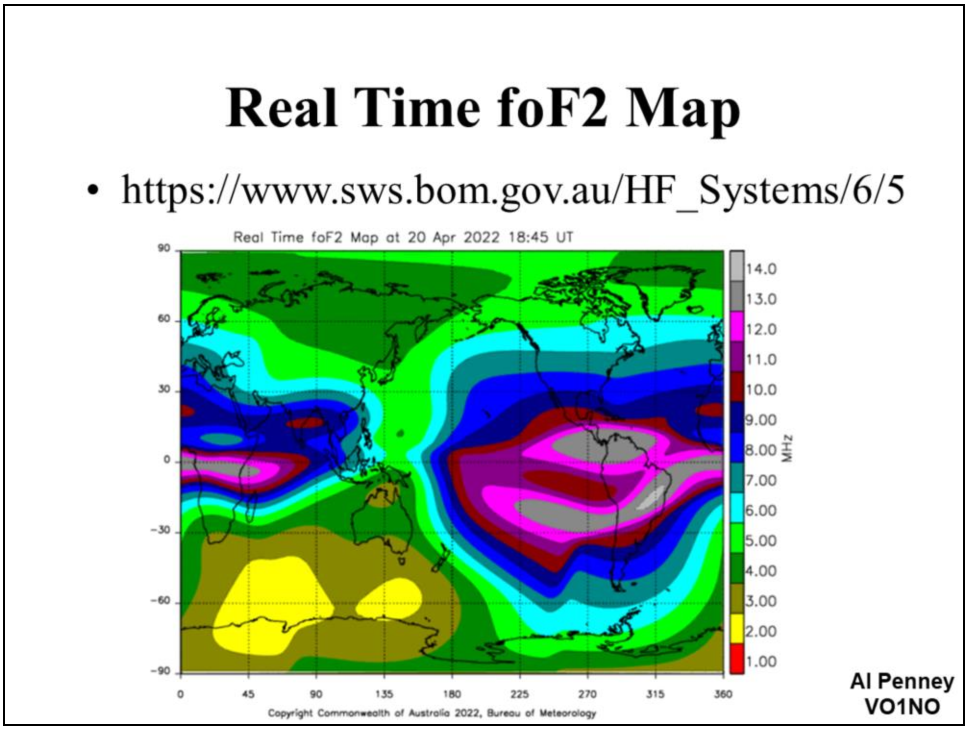
The **Canadian High Arctic Ionospheric Network (CHAIN)** is an array of ground-based radio instruments deployed in the Canadian Arctic and operated by the University of New Brunswick. The CHAIN instruments include high data-rate GPS receivers and digital ionosondes. After passing through the Earth's ionosphere, microwave GPS signals carry information about the total electron content (TEC). This information is commonly used to improve the precision of GPS and to study ionospheric morphology. Ionosondes transmit pulses of radio signals in the Medium Frequency (MF) and High Frequency (HF) ranges, whose echos are analyzed to measure height and density of the ionosphere. Advanced digital ionosondes used in the CHAIN network are also able to measure the bulk motion of ionospheric plasma.

Most of the CHAIN instruments are located within the polar cap defined as a region of open magnetic field lines. The polar cap ionosphere is directly linked to the interplanetary magnetic field carried by the solar wind. Polar cap thus provides a vantage point for the study of energy exchange between the solar wind, magnetosphere and ionosphere.

CHAIN is an integral part of the Canadian Geospace Monitoring (CGSM) programme. It provides ground support for Canadian and international scientific space missions such as THEMIS and CASSIOPE.

In January 2012, the Canada Foundation for Innovation announced funding for the Expanded Canadian High-Arctic Ionospheric Network (ECHAIN). This funding was used to add 15 Global Positioning System (GPS) receivers to the existing network of GPS receivers and radars of the Canadian High Arctic Ionospheric Network (CHAIN). The data will contribute significantly to the progress of space research by providing a better understanding of the processes in the Sun-Earth system.



Selected map: Ionospheric Map

The plot above shows a near real-time critical ionospheric frequency (foF2) map produced using automatically scaled ionogram profiles from the Australian region and around the world. The last 7 days of maps can be viewed using the control buttons underneath the above image.

The map shows colour contours of foF2 in units of MHz.

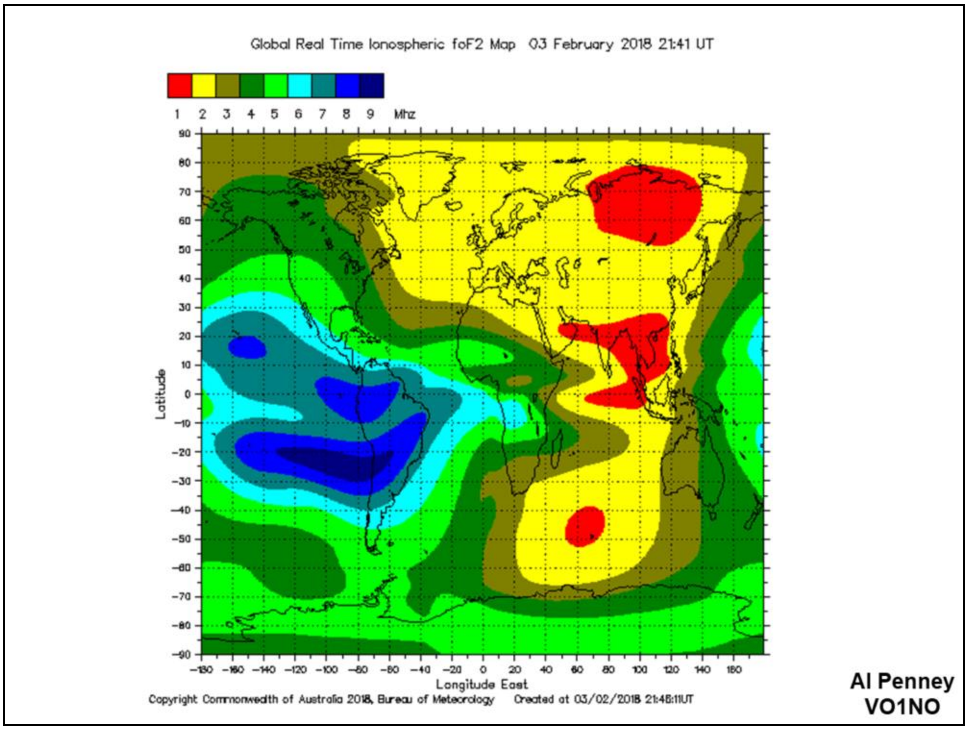
How to use this tool

1. Choose the type of map using the drop-down list located above the graph.
2. To animate, first select the display duration using drop-down list located below the graph and then press "Load Animation" button. The user can also choose different speeds of animations.
3. To view still images during a playing, press "Pause" button and then use the navigation buttons located below the graph to switch between images.

Data Providers for the World Ionospheric foF2 Map

(updated every 15minutes)

The data presented in this page are derived from the automated interpretation of ionograms from around the world. Regional data are obtained from the Space Weather Network (SWN), formely known as IPSNET, (Australia Pacific Region). Global data are obtained from the NICT Space Weather Information Centre of Japan (Japanese region), the Space Physics Group at Rhodes University's Hermanus Magnetic Observatory (South African region), the Istituto Nazionale di Geofisica e Vulcanolgia, Rome, Italy (Italian Region), the Facultad Regional Tucumn, Universidad Tecnolgica Nacional, Argentina, (South American Region), the Global Ionospheric Radio Observatory (GIRO), and the United States of America Space Weather Prediction Centre (SWPC). The ionospheric data available from the SWPC and GIRO are contributed by the International Space Environment Service's (ISES) Regional Warning Centres (RWCs) located around the globe, the United States Air Force (USAF) and several research institutes.



The following animated map shows how the colored frequency zones move from east to west. The animation will pause for 2-seconds on the last frame before looping.

Online Propagation Resources

- https://giro.uml.edu/
- https://www.voacap.com/hf/
- https://spaceweather.com/

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NVIS Antenna Pattern

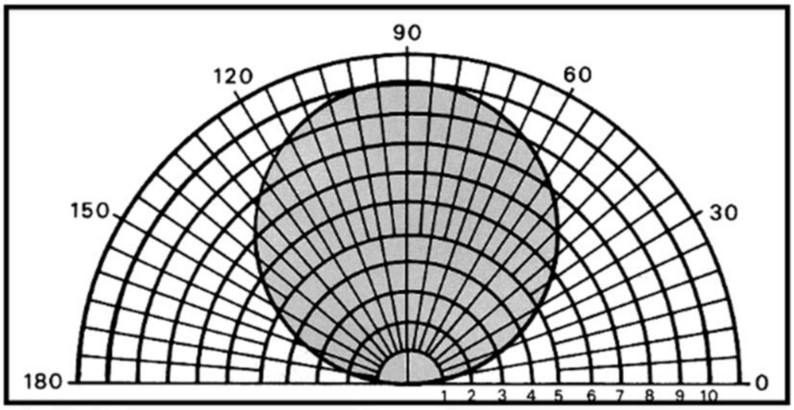

Figure M-4. Typical elevation plane pattern.

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Figure from *ARRL Antenna Handbook*, 22nd edition

Dipole near ground

- Higher antenna gives lower **takeoff angle**, good for DX. Rule of thumb: at least a half-wavelength above ground.
- Lower antenna is more omnidirectional in azimuth, and good for "near vertical-incidence skywave" (**NVIS**).
- Low antenna also called a "cloudwarmer".

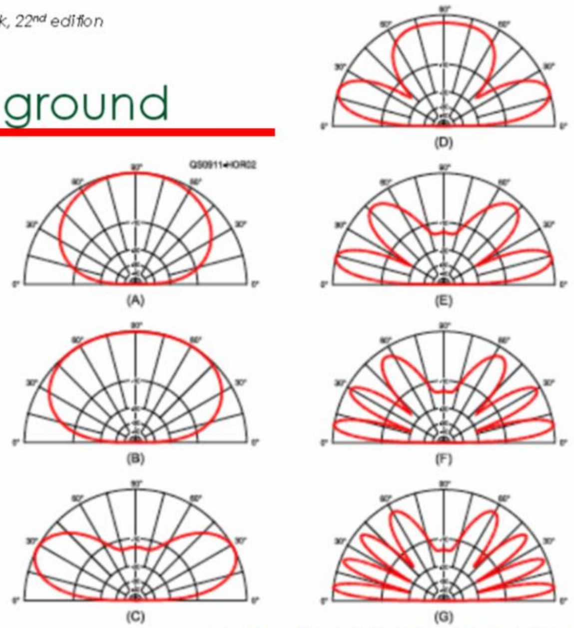

Figure 2.4 — Six radiation patterns for the dipole at different heights: (A) ⅛ λ, (B) ¼ λ, (C) ½ λ, (D) ¾ λ, E) 1 λ, (F) 1½ λ, (G) 2 λ.

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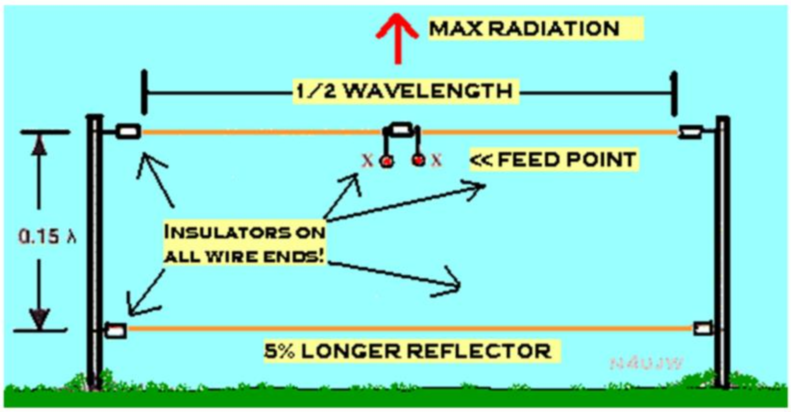
Simple NVIS Antenna



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Antennas[edit]

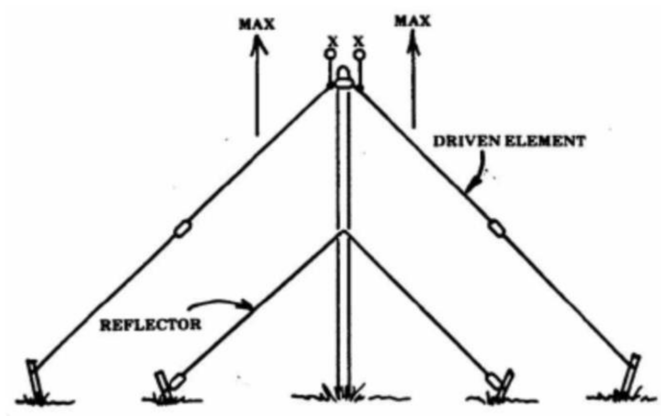
An NVIS antenna configuration is a horizontally polarized (parallel with the surface of the earth) radiating element that is from 1/20th wavelength (λ) to 1/4 wavelength above the ground. Optimum height is about 1/4 wavelength, and high angle radiation declines only slightly for heights up to about 3/8 wavelength. [6] That proximity to the ground forces the majority of the radiation to go straight up. Overall efficiency of the antenna can be increased by placing a ground wire slightly longer than the antenna parallel to and directly underneath the antenna. One source says that a single ground wire can provide antenna gain in the 3–6 dB range.[7] Another source indicates 2 dB for a single wire and nearly 4 dB for multiple ground wires.[8] Ground wires are more necessary when using lower dipoles over poor soils as without them considerable energy goes into heating the ground.

Depending on the specific requirements, various antennas (i.e. Sloper, T2FD, Dipole) can be used for NVIS communication, with horizontal dipoles or inverted V dipoles at about 0.2 wavelengths above ground giving the best results on transmit and at about 0.16 wavelengths on receive, according to military sources and an extensive study by Dutch researchers. [9] [10] Very low antennas are much inferior on transmit, less so on receive, where both noise and signal are attenuated.

Significant increases in communication will obviously be realized when both the transmitting station and the receiving station use NVIS configuration for their antennas. In particular for low profile operations NVIS antennas are a good option.[11]

For broadcasting, typical antennas consist of a dipole about 1/4 wavelength above ground, or arrays of such dipoles.[12] Up to 16 dipoles can be used, allowing strong signals with relatively low power by concentrating the signal in a smaller area. Limiting the coverage may be dictated by licensing, language or political considerations. Arrays of dipoles can be used to "slew" the pattern, so that the transmitter need not be in the center of the coverage footprint. Broadcast NVIS antennas usually use an extensive ground screen to increase gain and stabilize the pattern and feed impedance with changing ground moisture.

Inverted V NVIS with Reflector



Reflector is 5% longer than DE, spaced 0.15 WL below.

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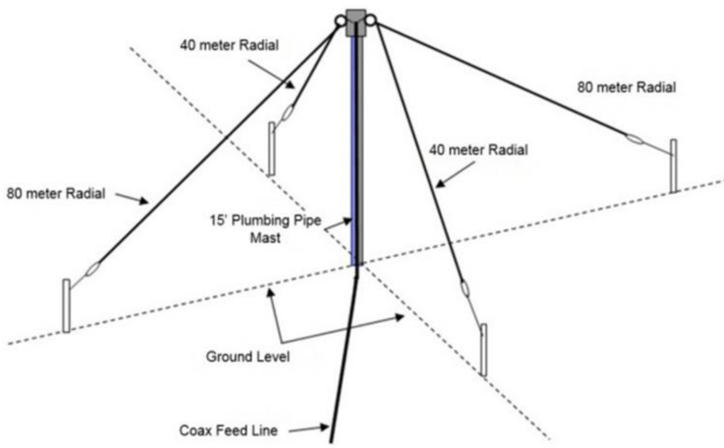
0.15 lambda is 6M on 40M, and 12M on 80M band.

Dual Band NVIS Antenna



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By "radial" they mean half of a dipole antenna in this illustration.

Shirley Antenna

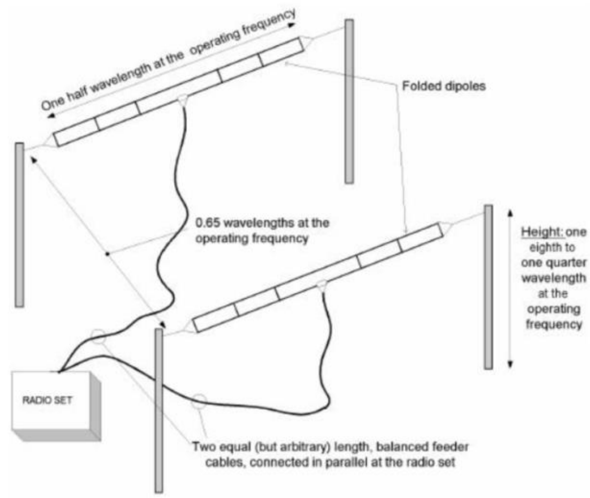

Fig.2 – a sketch

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The Shirley aerial.

The Malayan emergency led directly to the development of perhaps the best known NVIS aerial, and one of the most efficient. This is the Shirley, which is actually two phased dipoles with the ground as a reflector; further details are given in the appendix. In some respects it is the reference aerial for NVIS work. [See Fig.2 – Ed] It was designed in about 1950 by (the then) Major John Shirley, a New Zealander who was by all accounts a most enterprising and engaging character. At the time, he was serving in the Royal Signals and on attachment to the Army Operational Research Group in Malaya. The problem was communicating with small units in the jungle. The base station, in these operations, were usually outside the main jungle and relatively static. In addition, the same frequency could be used day and night (E region propagation, possibly?) and the opposition was not thought to have much in the way of a signals intelligence capability. After some thought and research, the Shirley aerial was the result. In Shirley's own words, 'the results were spectacular'. Although troublesome to construct – a problem obviously shared with any multi-element system - the Shirley aerial remained in the Army's repertoire for many years, and probably still does. As well as being used in Malaya, a classic example of the system is given in The Vital Link3 , during the Kenyan emergency. Communication had to be established across 50-100 miles, the area including the 12,000 foot high and thickly forested Aberdare

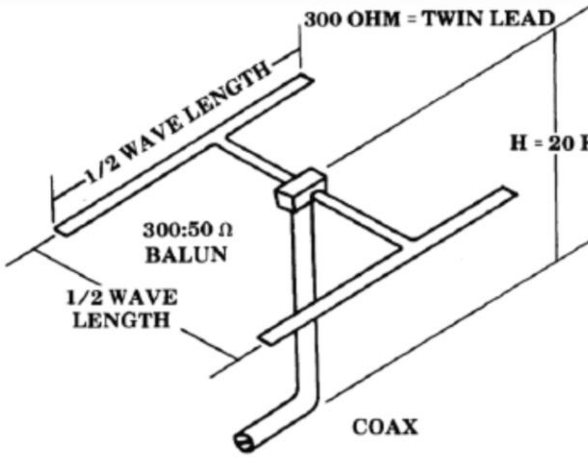
Mountains. Shirley aerials and the A510 were used ‘with good results.’

In its original and simplest form, the Shirley aerial seems to have comprised two half wave open dipoles, fed by twin mine detonating cable. An important factor
was ease of construction from readily available stores! In this configuration, the dipoles have a rather low input impedance and there must have been mismatches all
over the place. The whole system, however, could be resonated with the aid of the output tuning circuits in the transmitter. If necessary, the length of the feeders
could be altered, by equal amounts, to enable this to be done.

A development of the original version is to raise the input impedance by using folded dipoles. 150Ù twisted feeder can then be used to give an approximate 75Ù
match. Again, it seems possible to use a variety of more or less ad hoc feeders - including lighting flex, which often has an impedance of about the right figure.

The ultimate stage, perhaps, is to make the whole thing out of 300Ù ribbon, with a balun transformer in the middle.

US Army's Shirley Antenna



(A) SHIRLEY DIPOLE ARRAY

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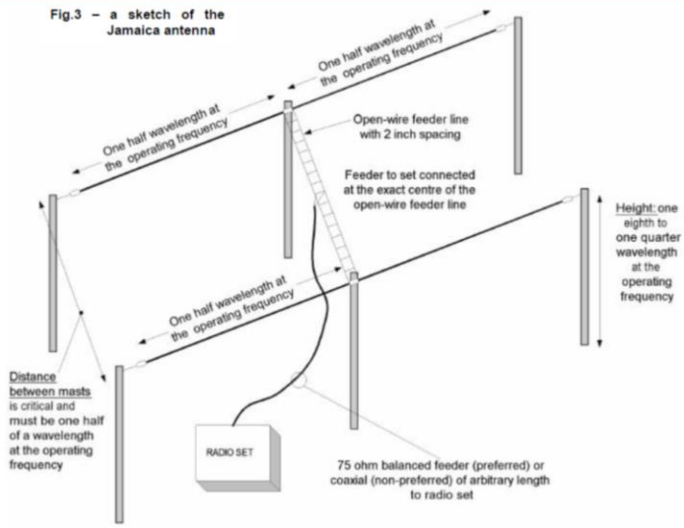
Jamaica Antenna



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The Jamaica

A relative of the Shirley is the Jamaica, so called from its use on that island. In this case, the dipoles are full wave, but it is otherwise similar in design.

NVIS – The Jamaica Antenna

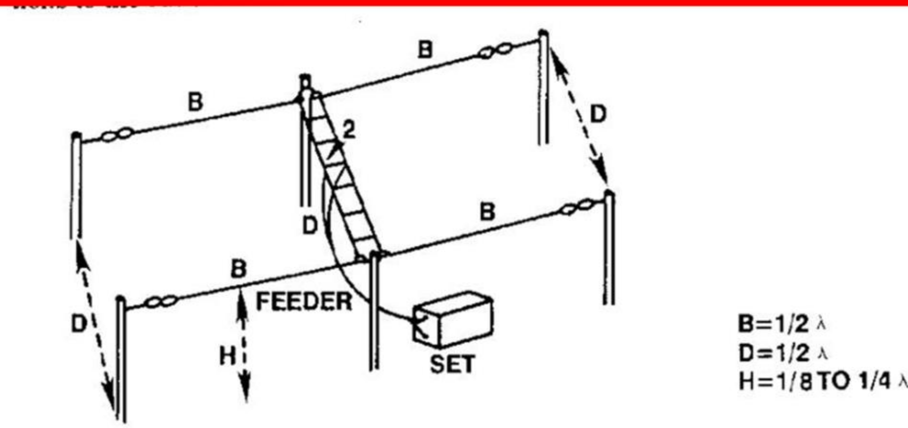

Figure 6. Jamaica antenna (Can be built from standard antenna kits AN/GRA-50; has four times the gain of the dipole antenna.)

Illustration courtesy of NVIS Communications (Worldradio Books)

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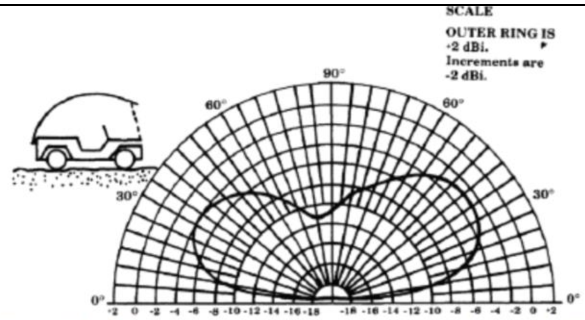

Figure 9. Far-field elevation pattern of vehicular 15 ft whip tied to front of vehicle at 10 MHz.

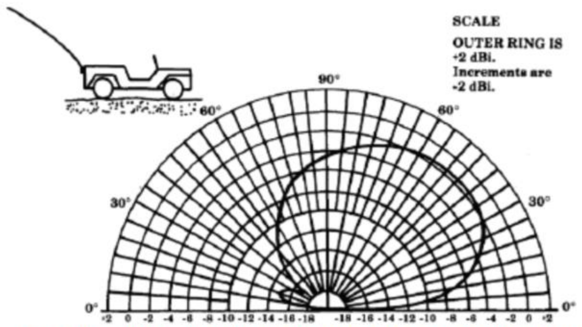

Figure 10. Far-field elevation pattern of vehicular 15 ft whip bent backwards at 45° at 10 MHz.

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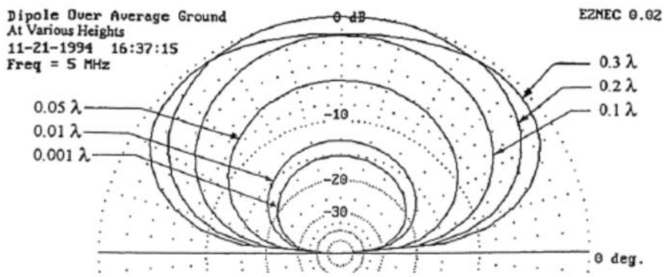
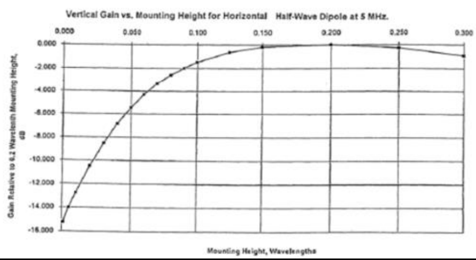
Optimum Height





0.2 Lambda height is optimum for NVIS

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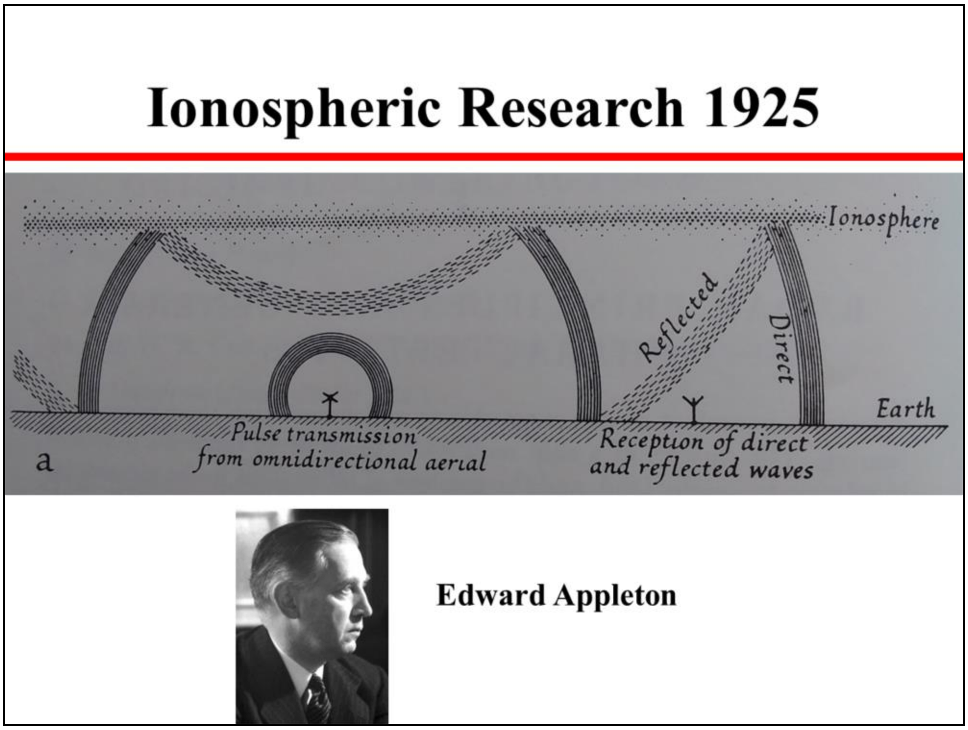
NVIS Antenna Relative Effectiveness

ANTENNA	CLEARING	75-FT FOREST	50-FT FOREST
λ/2 Unbalanced Single-Wire Dipole	+1.0	-2.8	-1.2, -1.7
λ/2 Balanced Single-Wire Dipole	+0.5	-3.7	No data
λ/2 Folded Dipole (300:50 ft balun)	+0.2	-1.0	No data
λ/4 Short (Loaded to /2) Dipole	-3.0	-5.2	No data
λ/2 Sleeve Dipole (on ground)	-32.1	-28.3	No data
3-Freq. Fan Dipole @ 15 ft	-0.4	-5.1	No data
3-Freq. Fan Dipole @ 12 ft	-2.4	-5.0	No data
3-Freq. Fan Dipole @ 9 ft	-4.0	-8.1	No data
Shirley Folded Dipole	+3.0	-0.3	No data
3 λ/4 Inverted L (1:h — 2:1)	-0.0	-2.8	No data
3 λ/4 Inverted L (1:h — 3:1)	-0.8	-3.3	No data
3 λ/4 Inverted L (1:h — 4:1)	-1.0	-5.8	No data
3 λ/4 Inverted L (1:h — 5:1)	-2.0	-0.3	-10.7, -12.5
30° Slant Wire (λ/4 elevated)	-10.1	-14.8	-13.5, -14.2
60° Slant Wire (λ/4 elevated)	-11.8	-14.8	No Data
10-ft Square (Vertical Plane) Loop @ 6 ft	-21.1	-25.3	No data
16.5-ft Whip	-41.5	-44.0	-25.0, -25.2

Table 1 shows the relative gain toward the zenith of the most common types of HF field-expedient antennas. This table shows that the ½-wave Shirley Folded Dipole (see Figure 6) has the most gain toward the zenith (with the other dipoles being almost as good). **The Shirley dipole is a good NVIS base station antenna, but it is limited to a band of frequencies within about 10 percent of the design frequency**.

The fan dipole (see Figure 6 and Table 1) performs almost as well and it provides more frequency flexibility (day, night, and transition period frequencies). For tactical communications, these dipoles can be easily deployed in a field-expedient manner because the can be located close to the ground. For mobile (or shoot and scoot) operations, vehicle-mounted antennas are required. The answer to this problem is the standard 16½-foot whip bent down into a horizontal position. In this configuration, the whip is essentially an asymmetrical dipole (with the vehicle body forming one side) located close to the earth, with a significant amount of energy being directed upward to be reflected back by the ionosphere in an umbrella pattern. For use while operating on the move, of course, the whip antenna must be tied across or parallel to the vehicle or shelter. This configuration is more like an asymmetrical open-wire transmission line, and it also will direct some energy upward – although with less efficiency. There are still no skip zones with proper frequency selection, but received signal levels are weaker than with the whip tied back. Special NVIS antennas designed primarily for helicopters are also useful for this application, and they can be modified for shelter and ground vehicular operation.

Traditionally, wire dipole antennas have always been sited so that the broadside of the antenna was pointed toward the receive station. This is the correct approach for long-haul paths. When using the NVIS mode, this antenna orientation is unnecessary. For NVIS operation, the antenna orientation does not matter since all the energy is directed upward and returns to earth in what is essentially an omnidirectional pattern. In operational terms this means that the dipole should be erected at any orientation that is convenient at the particular radio site without regard to the bearing of other stations. This holds true except when operating in the region of the "magnetic dip equator." When operating within 500 km of the dip equator, the dipole antenna should be oriented in a magnetically north-south direction for greater received signal levels for all NVIS path bearings. US Army Special Forces made use of this dipole north-south orientation in their HF single sideband (SSB) net in the Mekong delta during the Vietnam War with excellent results. Traditional antenna orientation (broadside to the path direction) must be retained when operating on longer skywave paths near the dip equator and elsewhere.



The existence of a reflecting atmospheric layer was not in itself a completely new idea. Balfour Stewart had suggested the idea in the late 19th century to explain rhythmic changes in the earth's magnetic field. More recently, in 1902, Oliver Heaviside [3] and Arthur E. Kennelly had suggested such a electromagnetic-reflecting stratum, now called the Kennelly-Heaviside layer, may explain the success Marconi [4] had in transmitting his signals across the Atlantic. Calculations had shown that natural bending of the radio waves was not sufficient to stop them from simply "shooting off" into empty space before they reached the receiver. Appleton thought the best place to look for evidence of the ionosphere was in the variations he believed it was causing around sunset in radio signal receptions. It was sensible to suggest these variations were due to the interference of two waves but an extra step to show that the second wave causing the interference (the first being the ground wave) was coming down from the ionosphere. The experiment he designed had two methods to show ionospheric influence and both allowed the height of the lower boundary of reflection (thus the lower boundary of the reflecting layer) to be determined.

German NVIS – WW2

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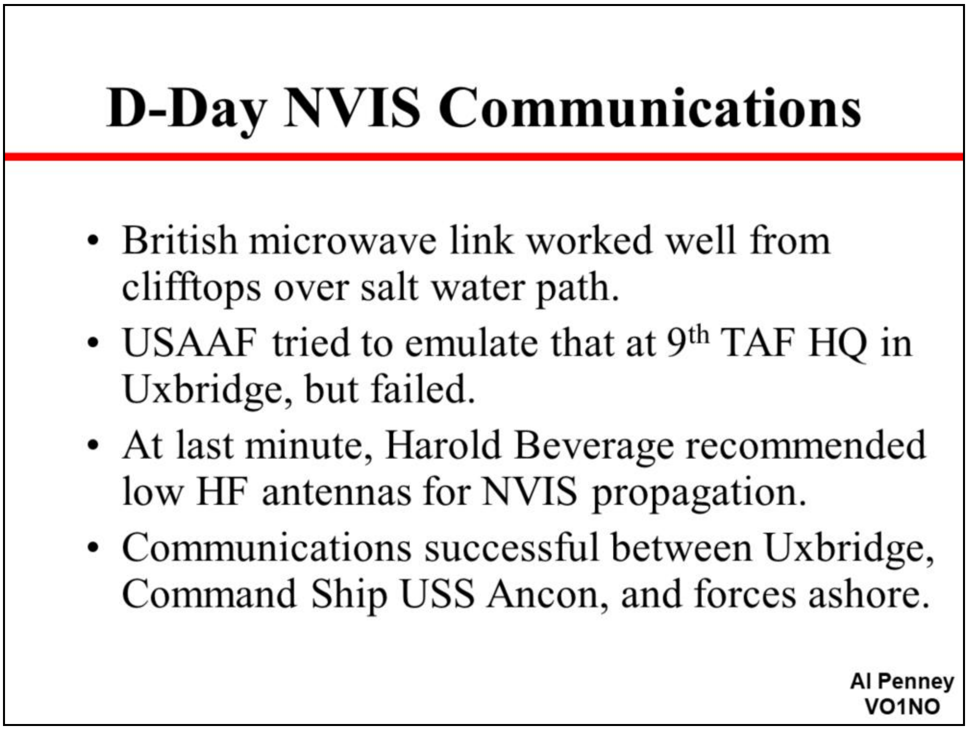
NVIS was first discovered or developed by the German Army in World War Two, while they were engaged with the Soviet Union on the Eastern Front. What they found was that while their excellent upper HF/lower VHF radios, developed during the late 1930s during the run-up to the solar peaks of Cycle 17 (1937 to 1939) worked very well for long haul HF communication, they had great difficulty using these radios for intermediate communication between groups or columns; their columns were often too far away for LOS communication and too close for HF skip. Amateur operators (Hams) today call that being in the “skip Zone.”

Here is a photograph of Heinz Guderian’s command vehicle showing a NVIS cage antenna. One can also see the extendable mast used for VHF in the center.



D-Day, North Africa and Italy

Beverage:

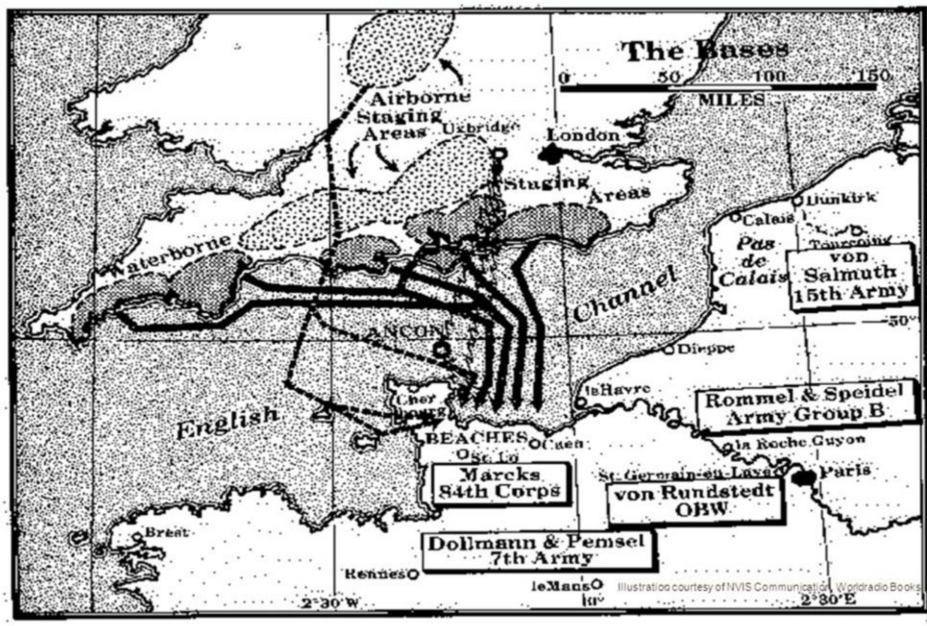
Yeah, a lot of funny things happened when I was over in North Africa. It was about two or three days before D-Day, and what did I find? Well, to go back a little bit. The British had their communications system over the seas to France on the Isle of Wight, way up on the top of the cliffs, overlooking the saltwater. Microwaves they used. They worked fine because of the high conductivity of the sea. Well, I found out that the Americans were very foolishly trying to duplicate that over land. They were going about 17 miles inland, and it would poop out in about a mile over land — poor conductivity. Over saltwater it was fine. So, D-Day was due any minute. I had to do something fast.

Nebeker:

Did they call you in for that purpose?

Beverage:

Yes. I had a couple of days to get something working for the landing of our troops. I recalled working with the Bell Labs one time down in the Florida jungle on how to communicate out of a jungle when your horizontal wires are low, just above the ground, and they shot this thing up into the sky. And so we got out on the sky wave. So, as I say, I had a day or two days somehow to get the work going for the invasion of the continent. The only thing I could think of was to duplicate the work we did down there in Florida, to use a long horizontal antenna and use that for communications from headquarters to the ships and the ships back to the headquarters. So I set it up, and on D-Day the head of the Air Force asked me to come out there to Uxbridge. As I say, it was from Uxbridge in the direction of France several miles overland. I didn't know how good it would work. I was very worried because if it didn't work I would feel guilty if hundreds of our boys in trying to land on the beach got killed. I'd feel I was guilty. So I was worried sick, and on D-Day I didn't know what the hell was going on. I really was very, very worried. Finally the general in charge of the Air Force came in and said, "Well, my boy, thanks to you there was no difficulty in the landing of our troops on the continent." Boy! The delight! Did that relieve me that morning when I found out I did something useful instead of something foolish. Oh, boy! That was a wonderful relief.



D-Day

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Distance from Uxbridge to Normandy = 260 km (160 miles)


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USS Ancon off Omaha beach head - June 1944.

USS Mount Whitney – current day

American Experience Vietnam

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Traditionally, wire dipole antennas have always been sited so that the broadside of the antenna was pointed toward the receive station. This is the correct approach for long-haul paths.

- When using the NVIS mode, this antenna orientation is unnecessary. For NVIS operation, the antenna orientation does not matter since all the energy is directed upward and returns to earth in what is essentially an omnidirectional pattern.
- In operational terms this means that the dipole should be erected at any orientation that is convenient at the particular radio site without regard to the bearing of other stations**.**
- **This holds true except when operating in the region of the "magnetic dip equator."** When operating within 500 km of the dip equator, the dipole antenna should be oriented in a **magnetically north-south direction for greater received signal levels for all NVIS path bearings**.
- US Army Special Forces made use of this dipole north-south orientation in their HF single sideband (SSB) net in the Mekong delta during the Vietnam War with excellent results.
- Traditional antenna orientation (broadside to the path direction) must be retained when operating on longer skywave paths near the dip equator and

elsewhere.

Interesting US Army designs came out of Vietnam War – articles in QST in late 1960s / early 1970s

- Small HF Transmit Loops
- Using trees as vertical antennas

NVIS Summary

- Proven and effective communications within several hundred km.
- Ideal for emergencies and mountains.
- 80m, 60m, 40m most common NVIS bands.
- Consult ionogram for frequency selection.
- May need day and night frequencies.
- Antennas generally simple and easy to set up.

Questions?

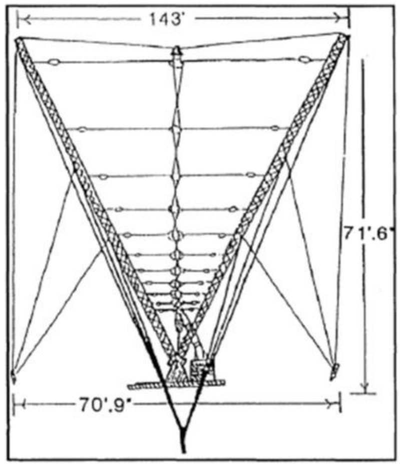
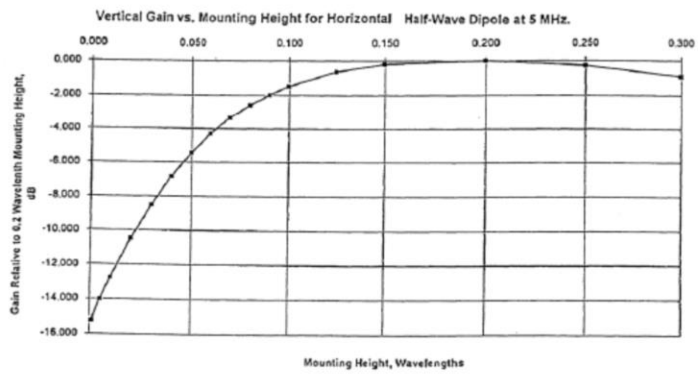


Figure 3. The LPH-15 Tactical Vertically Aligned Horizontal Log Periodic High Angle Antenna for Short to Medium Distances

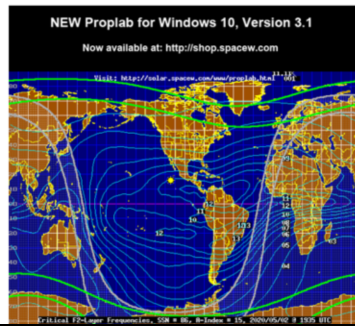
**Al Penney
VO1NO**


Vertical Gain vs. Mounting Height for Horizontal Half-Wave Dipole at 5 MHz.
0.000
0.050
0.100
0.150
0.200
0.250
0.300
0.000
-2.000
-4.000
-6.000
-8.000
-10.000
-12.000
-14.000
-16.000
Gain Relative to 0.2 Wavelenth Mounting Height, dB
Mounting Height, Wavelengths

Ionosonde Data

- Used to be able to use foF2 map here, but now requires you to purchase software:

http://www.spacew.com/www/fof2.html



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Near-Real-Time F2-Layer Critical Frequency Map

The following image is a recent high-resolution global map of F2-layer critical frequencies. This corresponds to the maximum radio frequency that can be reflected by the F2-region of the ionosphere at vertical incidence (that is, when the signal is transmitted straight up into the ionosphere). It is also a map showing the current location of the auroral ovals, the sunrise/sunset terminator and the regions of the world where the sun is 12 degrees below the horizon (which estimates the gray-line corridor where HF propagation is usually enhanced). This is one of a plethora of constructable maps that is produced by *PROPLAB-PRO Version 2.0* (formerly known as SKYCOM PRO), a very powerful radio propagation software package for IBM or compatible computers, ideal for amateur or professional radio communicators.

Using this Map

This map can be used to determine the frequencies that will **always** be returned to the Earth. Transmitted frequencies *higher* than the indicated contours (which are given in MHz) may penetrate the ionosphere, resulting in lost power to space.
Frequencies *lower* than the indicated contours will never penetrate the ionosphere.
Lower foF2 values indicate a weaker ionosphere and correspond to regions with lower Maximum Usable Frequencies (MUFs). Higher foF2 values indicate a stronger ionosphere and correspond to regions with higher MUFs.It is important to remember that these contours refer to the transmitted signals that are vertically incident on the ionosphere. All long-distance communications use signals that are obliquely incident

on the ionosphere (that is, the radio signals are passing through the ionosphere at an angle instead of head-on).

The purpose of this map is to help illustrate regions of the ionosphere that are weak and strong. Critical F2 layer frequencies in excess of about 8 MHz correspond to regions of the ionosphere that are relatively strong and capable of reflecting high-frequency signals over longer distances. Critical frequencies below about 4 MHz are weaker and will result in greater signal loss to space, lower MUFs and greater signal instability.

The map shows the ***radio auroral zones*** as green bands near the northern and southern poles. The area within the green bands is known as the auroral zone. Radio signals passing through these auroral zones will experience increased signal degradation in the form of fading, multipathing and absorption.

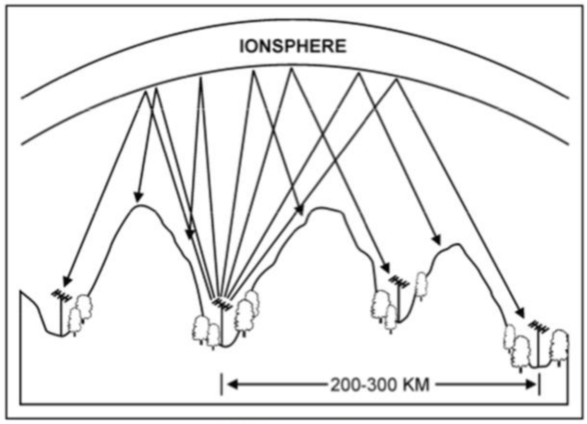
The radio auroral zones are typically displaced equatorward from the *optical* auroral zones (or the regions where visible auroral activity can be seen with the eye).

The great-circle signal path from the Eastern United States to Tokyo is shown along with the distance of the path (in km) and the bearing from the U.S. to Tokyo (in degrees from north).

If this signal path crosses through the green lines indicating the position and width of the radio auroral zones, propagation will be less stable and degraded compared to if the signal never crossed through the auroral zones. Using your mouse, PROPLAB-PRO will let you plot the great-circle paths and azimuths between any two points *while this display is continually updated.*

The ***yellow Sun symbol*** near the equator indicates the location where the Sun is directly overhead. The regions of the world where the Sun is exactly ***rising or setting*** is known as the ***Grayline*** and is shown as the solid gray-colored line that is closest to the Sun symbol. The second solid gray-colored line defines the regions of the world where the Sun is exactly 12 degrees below the horizon. This line defines the end of ***evening twilight***. Everything inside of this second line is experiencing night-time conditions. The area between the two lines (shaded a lighter shade than the night-time sector) is known as the ***grayline*** and has special significance to radio communicators. Signals which travel *inside* the grayline region often experience significant improvements in propagation because of the loss of ionization in the D-region as the Sun sets. However, because the higher F-regions of the ionosphere remain strongly ionized for longer periods of time, signals with higher frequencies are able to travel to greater distances with less attenuation when they are within the grayline. The ***great-circle path*** from the eastern U.S. to Japan is also shown with the accompanying ***distance*** (in kilometers) and ***bearing*** (clockwise from north). Notice how this path may occassionally pass into the influential auroral zones if geomagnetic activity increases or during the night-times.

NVIS Propagation



NVIS propagation

Al Penney
VO1NO

Near vertical incidence skywave, or **NVIS**, is a skywave radio-wave propagation path that provides usable signals in the distances range — usually 0–650 km (0–400 miles). It is used for military and paramilitary communications, broadcasting,[1] especially in the tropics, and by radio amateurs for nearby contacts circumventing line-of-sight barriers. The radio waves travel near-vertically upwards into the ionosphere, where they are refracted back down and can be received within a circular region up to 650 km (400 miles) from the transmitter.[2] If the frequency is too high (that is, above the critical frequency of the ionospheric F layer), refraction fails to occur and if it is too low, absorption in the ionospheric D layer may reduce the signal strength.

There is no fundamental difference between NVIS and conventional skywave propagation; the practical distinction arises solely from different desirable radiation patterns of the antennas (near vertical for NVIS, near horizontal for conventional long-range skywave propagation).

The most reliable frequencies for NVIS communications are between 1.8 MHz and 8 MHz. Above 8 MHz, the probability of success begins to decrease, dropping to near zero at 30 MHz. Usable frequencies are dictated by local ionospheric conditions, which have a strong systematic dependence on geographical location. Common bands used in amateur radio at mid-latitudes are 3.5 MHz at night and 7 MHz during daylight, with experimental use of 5 MHz (60 meters) frequencies. During winter nights at the bottom of the sunspot cycle, the 1.8 MHz band may be required. [3] Broadcasting uses the tropical broadcast bands between 2.3 and 5.06 MHz, and the international broadcast bands between 3.9 and 6.2 MHz. Military NVIS communications mostly take place on 2–4 MHz at night and on 5–7 MHz during daylight.

Optimum NVIS frequencies tend to be higher towards the tropics and lower towards the arctic regions. They are also higher during high sunspot activity years. The usable frequencies change from day to night, because sunlight causes the lowest layer of the ionosphere, called the D layer, to increase, causing attenuation of low frequencies during the day [4] while the maximum usable frequency (MUF) which is the critical frequency of the F layer rises with greater sunlight. Real time maps of the critical frequency are available. [5] Use of a frequency about 15% below the critical frequency should provide reliable NVIS service. This is sometimes referred to as the optimum working frequency or FOT.

NVIS is most useful in mountainous areas where line-of-sight propagation is ineffective, or when the communication distance is beyond the 50 mile (80 km) range of groundwave (or the terrain is so rugged and barren that groundwave is not effective), and less than the 300–1500 mile (500–2500 km) range of lower-angle sky-wave propagation. Another interesting aspect of NVIS communication is that direction finding of the sender is more difficult than for ground-wave communication (i.e. VHF or UHF). For broadcasters, NVIS allows coverage of an entire medium-sized country at much lower cost than with VHF (FM), and daytime coverage, similar to mediumwave (AM broadcast) nighttime coverage at lower cost and often with less interference.