NVIS Antenna Design

Theory, Modeling, and Practical Applications

By W5JCK

Preface

I am very much indebted to the research and data from many hams, especially the notes of L. B. Cebik, W4RNL, SK (2008).

Scope of this Presentation

This presentation will do the following:

- Examine NVIS antenna theory
- Examine antenna models
- Provide a basis for determining antenna installations

This presentation will *NOT* do the following:

- Suggest which antenna is best
- Provide construction details for antennas

Presentation Outline

1. Scope of Presentation
2. What is NVIS?
3. Terminology
4. Skywaves & Ground waves
5. Usable bands for NVIS
6. Basic design criteria
7. Debunking the Reflector Myths
8. Fixed stations
9. Field stations
10. Size restrictions and limitations

What is NVIS?

- NVIS stands for Near-Vertical Incidence Skywave radio propagation.
- NVIS is used for short range communications, that is out to about 200 to 300 miles.
- The many purposes for NVIS propagation includes military communications and emergency communi-cations (EMCOMM).

Some Really Boring Terms

- Maximum Usable Frequency (MUF)
- Critical Angle of Radiation
- Vertical-Incidence Critical Frequency

Maximum Usable Frequency (MUF)

- The highest frequency at any given time and for any given set of circumstances that can be refracted off the ionosphere
- MUF is constantly changing
- Frequencies higher than the MUF will pass through the ionosphere and be heard by ET

Critical Angle of Radiation

- The steepest angle at which a radio signal can be refracted by the ionosphere at any given time and for any given set of circumstances
- Critical Angle of Radiation is constantly changing
- Radio signals at angles greater than the Critical Angle of Radiation will pass through the ionosphere and be heard by ET

Vertical-Incidence Critical Frequency

- The MUF for local skywave high-angle communication
- Vertical-Incidence Critical Frequency is constantly changing
- Vertical-Incidence Critical Frequency ***averages*** between 2 and 13 MHz for the F-layer, ranging from 2 MHZ during nighttime at the lowest point of the solar cycle to 13 MHz during the daytime at the highest point of the solar cycle

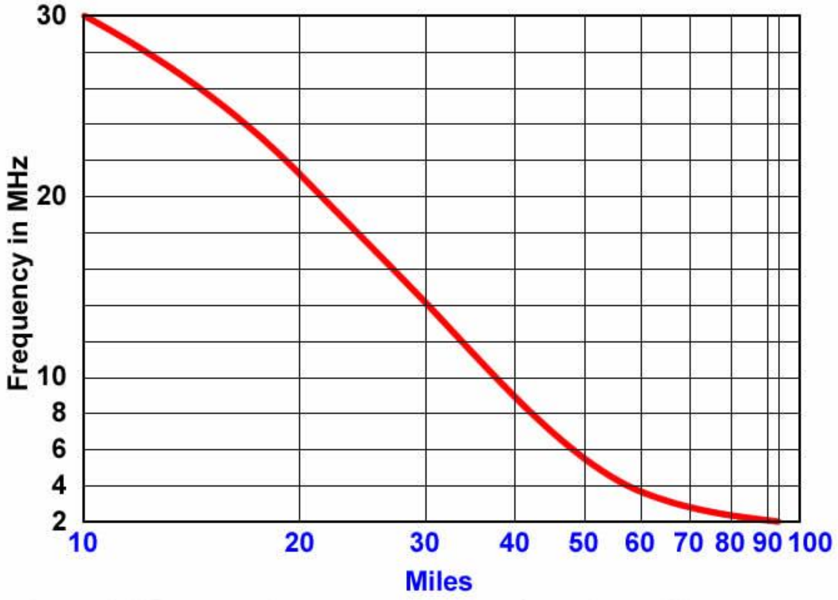
Skywaves & Ground waves

Antennas produce two kinds of radio propagation waves:

- Skywaves
- Ground waves

Ground wave propagation

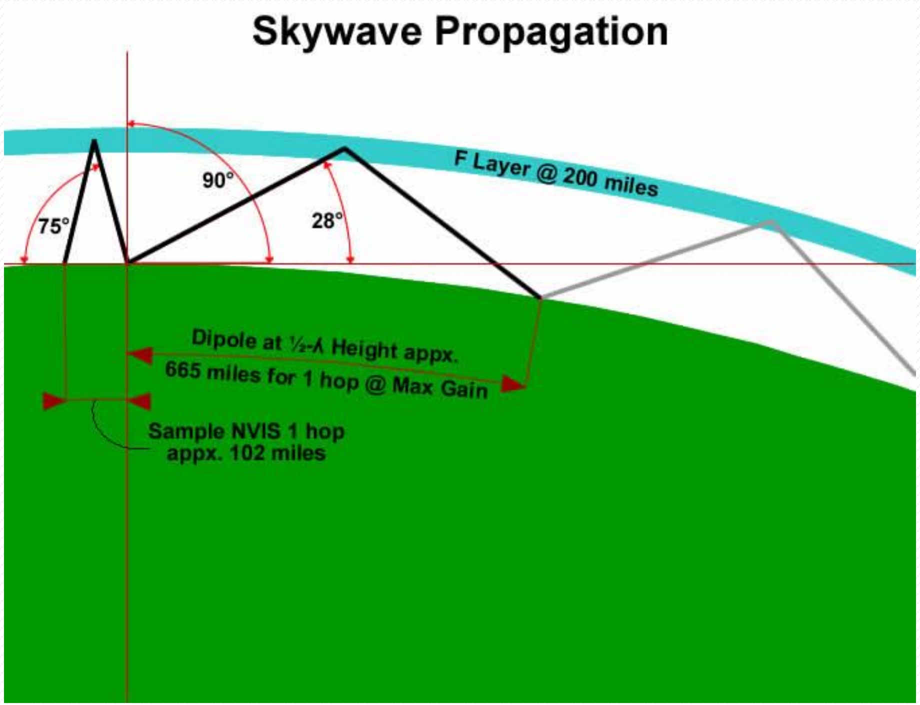
- Ground waves travel close to the ground
- Ground waves bend downward slightly more than the curvature of the Earth
- As frequency increases, maximum ground wave distance decreases



Typical HF groundwave range as a function of frequency

Skywave propagation

- Solar radiation creates free electrons and positively charged ions in the ionosphere
- When the ionization is dense enough, and the radio wavelength is long enough, the radio wave is bent back toward Earth
- Daytime conditions usually favor the 40m ham band
- Nighttime conditions usually favor the 80m ham band



Usable Ham Bands for NVIS

Not all ham bands or reliable for NVIS communication. So let us examine the best bands to use, and when.

Which bands should I use?

- Remember that Vertical-Incidence Critical Frequency ***averages*** between 2 and 13 MHz, so we can eliminate 20m band and all higher bands.
- 30m is marginal, and 160m requires a huge antenna , so we can eliminate them as well.
- That leaves us with the 80m, 60m, and 40m bands that are traditionally used for reliable NVIS operation.

What time is best for each band?

- The D Layer exists during the daytime, then fades away after dark. Since the D Layer absorbs radiation in the upper MF and lower HF range, it makes 80m unreliable for NVIS operation during the daytime. After dark when the D Layer dissipates, 80m becomes reliable.
- During the daytime 40m is reliable for NVIS operation. However, it is not reliable at nighttime.

What time is best for each band?

- There is a lag time between daytime and nighttime, and vice versa, when 80m and 40m can be unreliable. 60m can fill this void. However, it is low power (50 watts PEP) and amateur radio can only use it on a secondary basis.

To sum up: Useable NVIS Bands

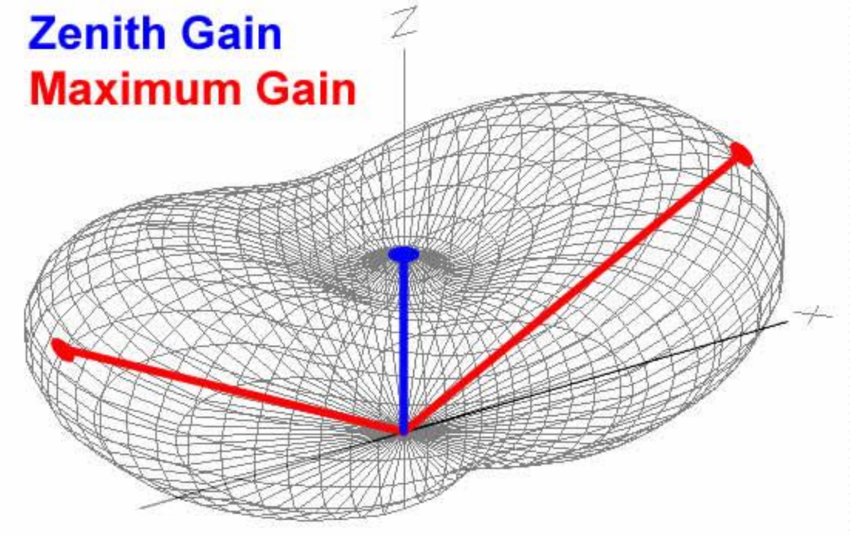
- **Daytime:** 40m is the most reliable
- **Twilight:** While the D Layer dissipates, 60m might be reliable
- **Nighttime:** 80m is the most reliable
- **Dawn:** While the D Layer is forming, 60m might be reliable

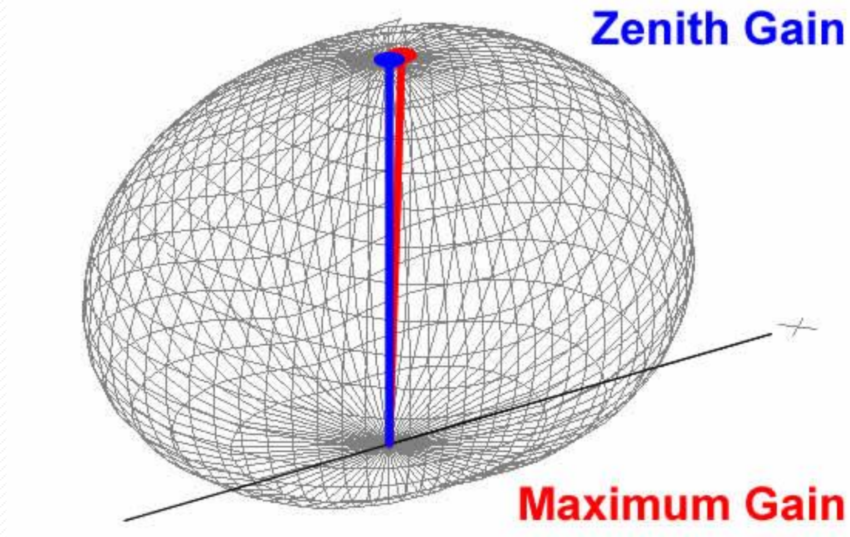
NVIS Antenna Design Criteria

- Maximum Gain and Zenith Gain
- Broadside and Endwire Beamwidths (Radiation Pattern)
- Bandwidth
- Installation Height above Ground
- Ground (Soil) Quality

Maximum Gain and Zenith Gain

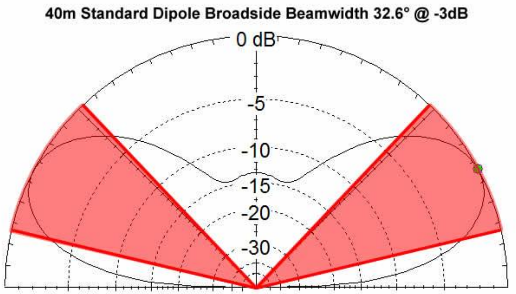
Dipole ½-ʎ above ground **NVIS dipole**

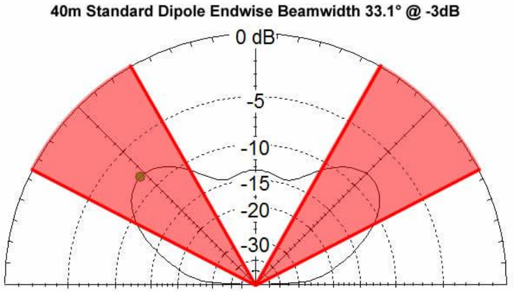




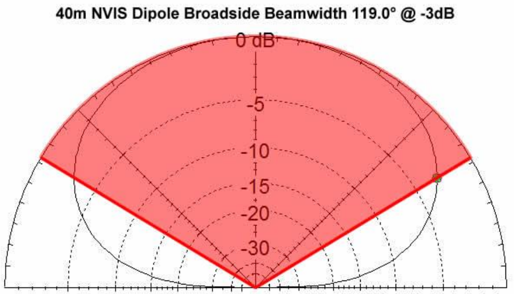
2D Beamwidths (max. gain to -3 dB)

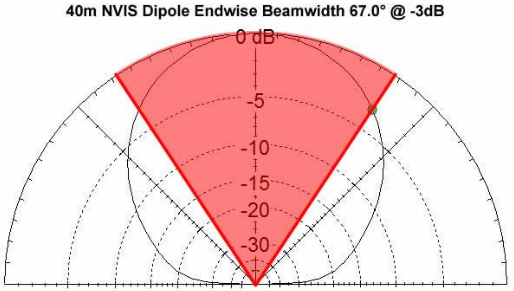
Dipole ½-λ above ground





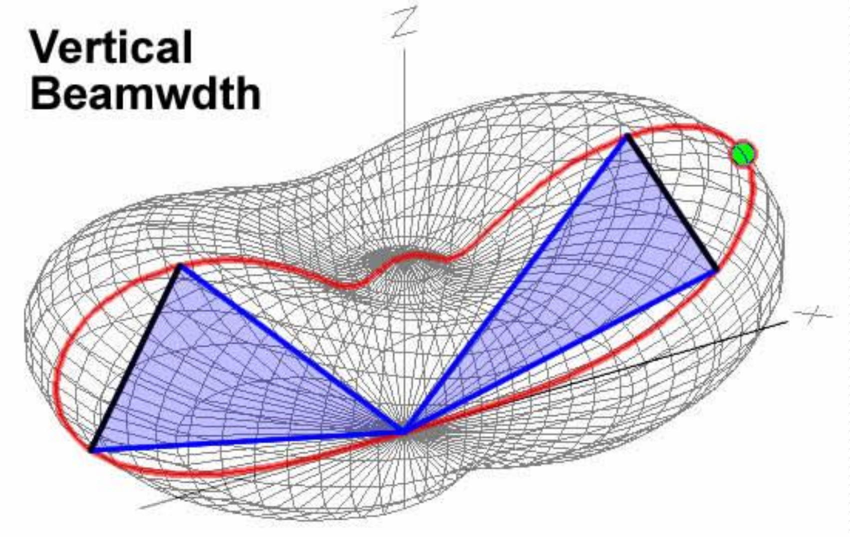
NVIS dipole



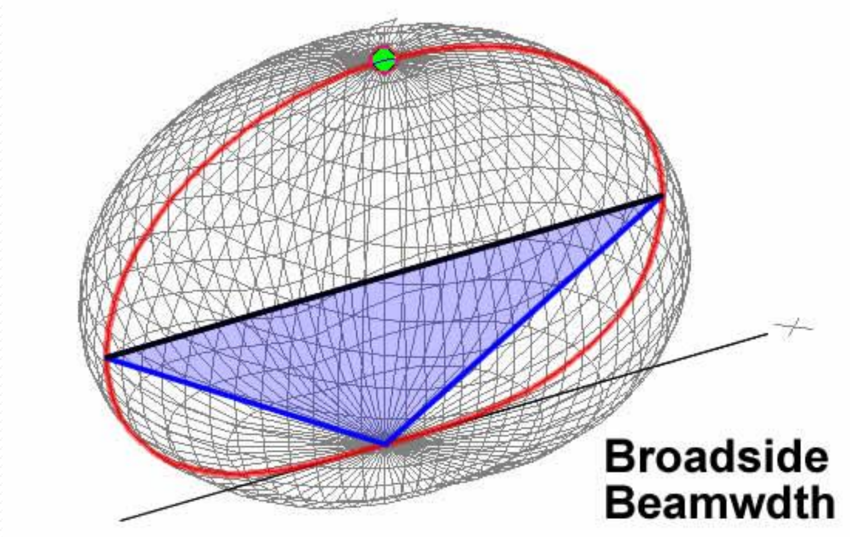


3D Beamwidths Broadside to Wires

Dipole ½-ʎ above ground

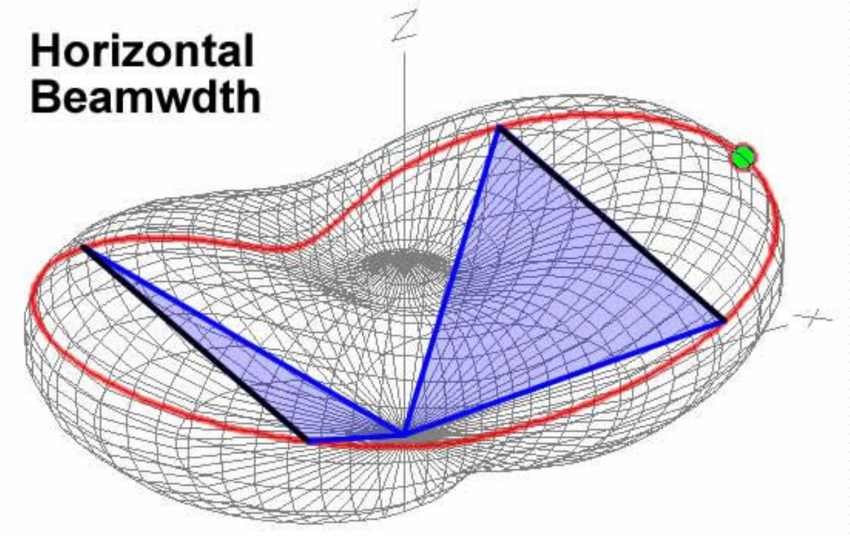


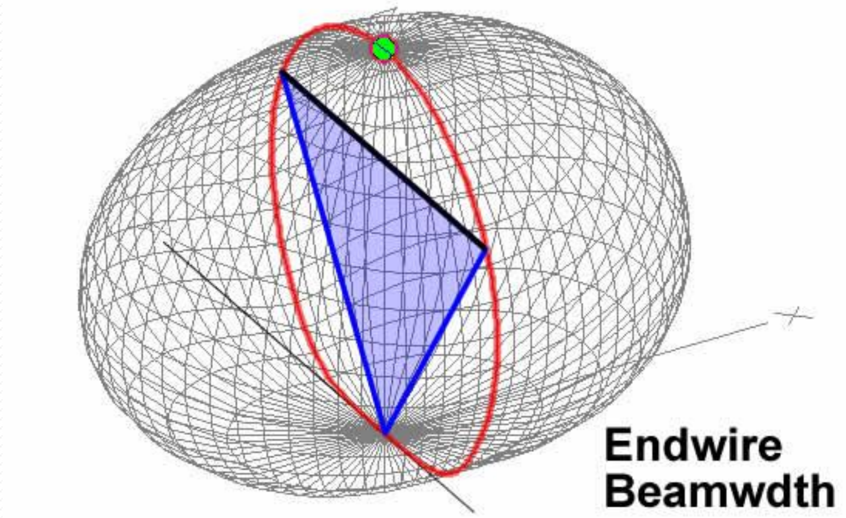
NVIS dipole



3D Beamwidths (horiz. & endwire)

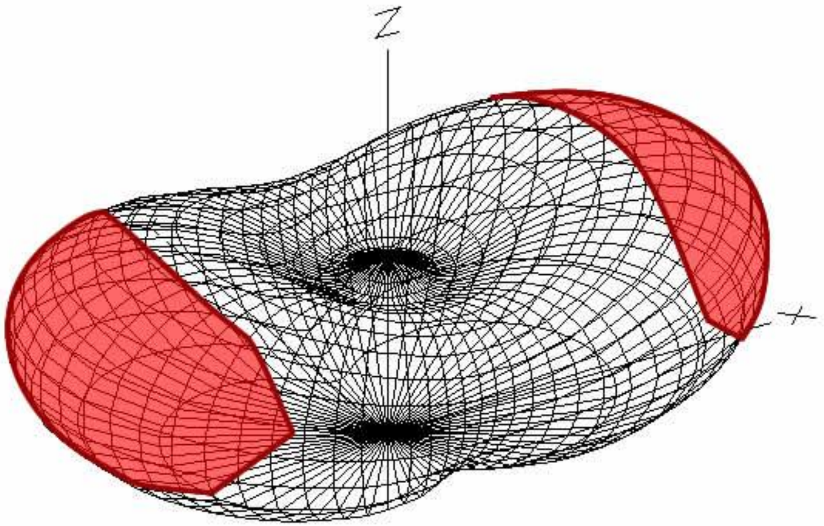
Dipole ½-ʎ above ground **NVIS dipole**



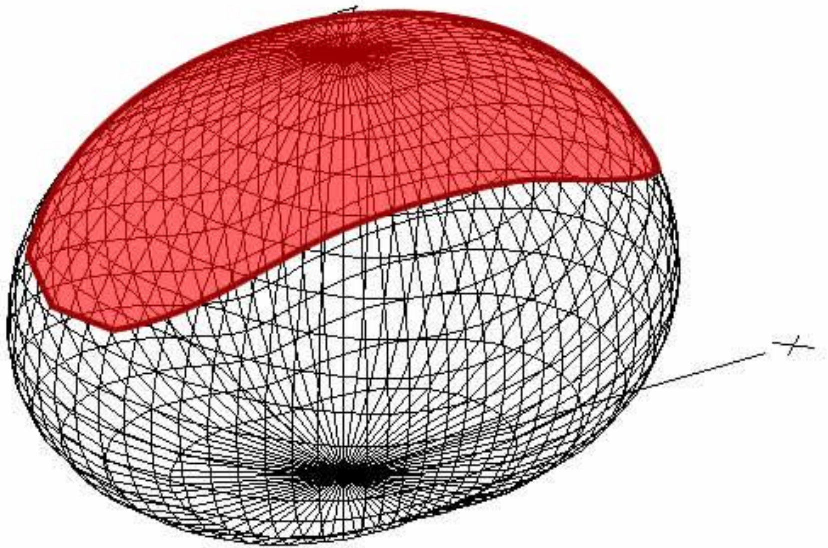


3D Radiation Pattern

Dipole ½-ʎ above ground

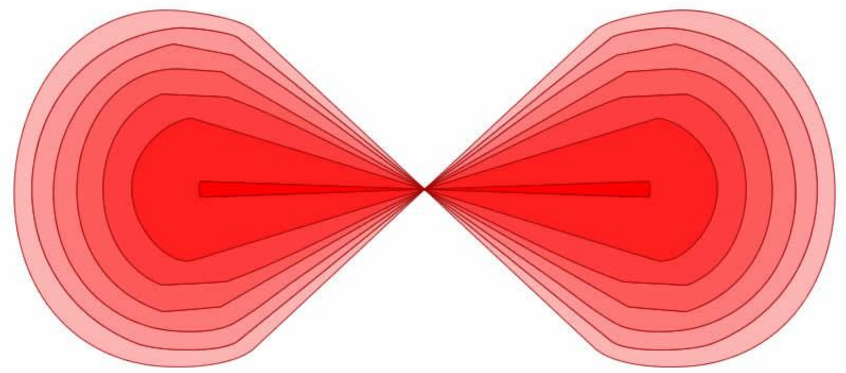


NVIS dipole

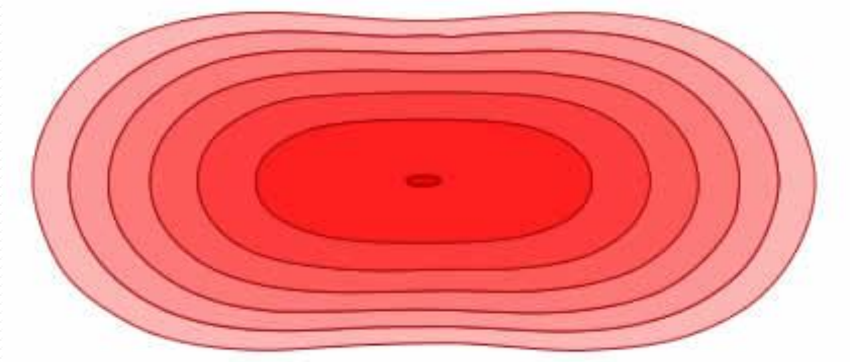


Propagation Patterns

Dipole ½-ʎ above ground

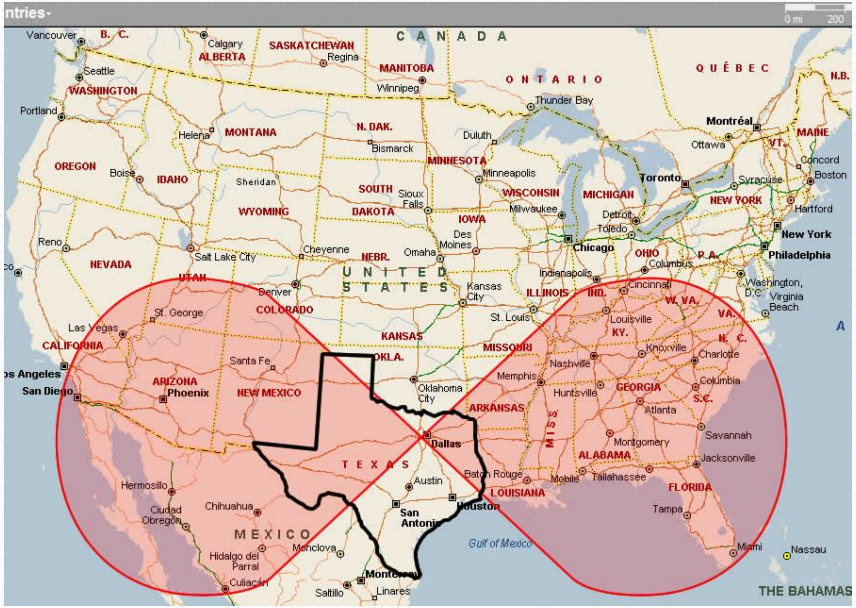


NVIS dipole

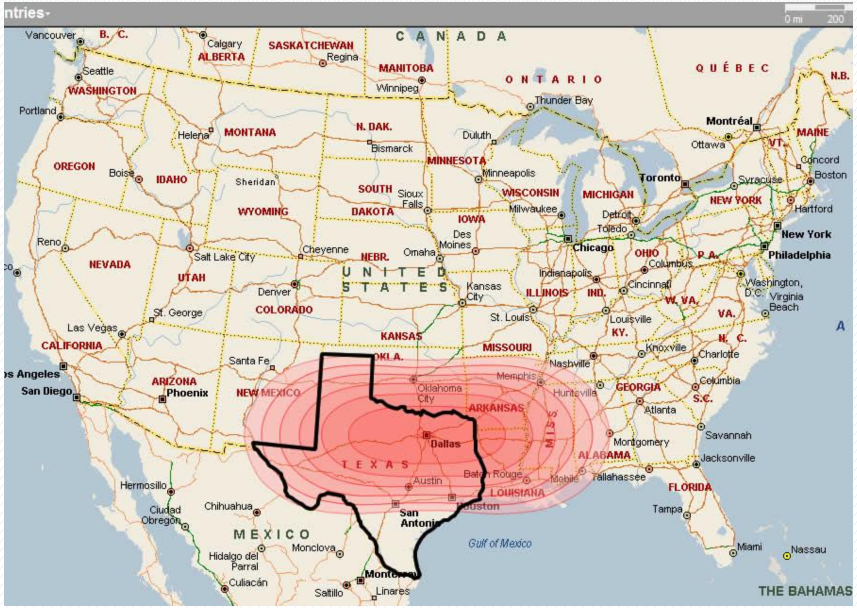


Mapped Propagation Patterns 1

Dipole ½-ʎ above ground

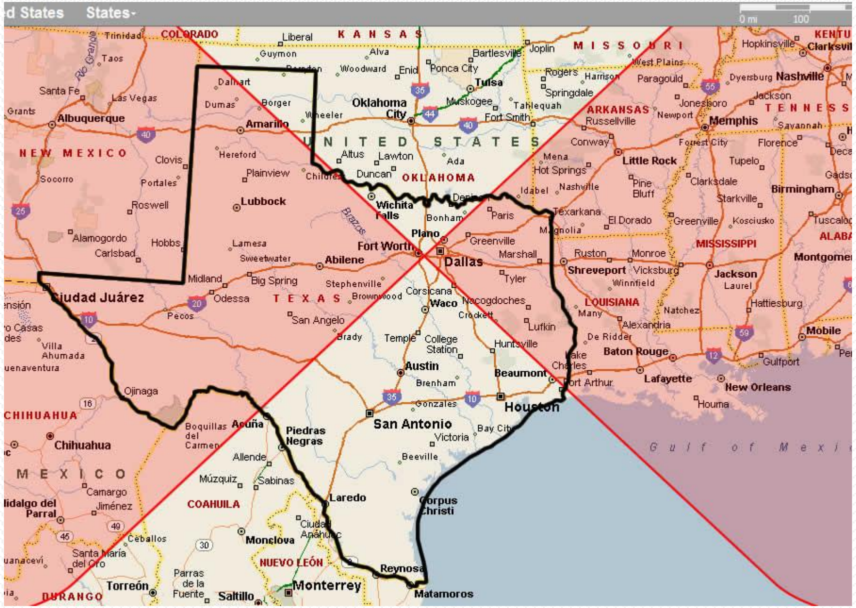


NVIS dipole

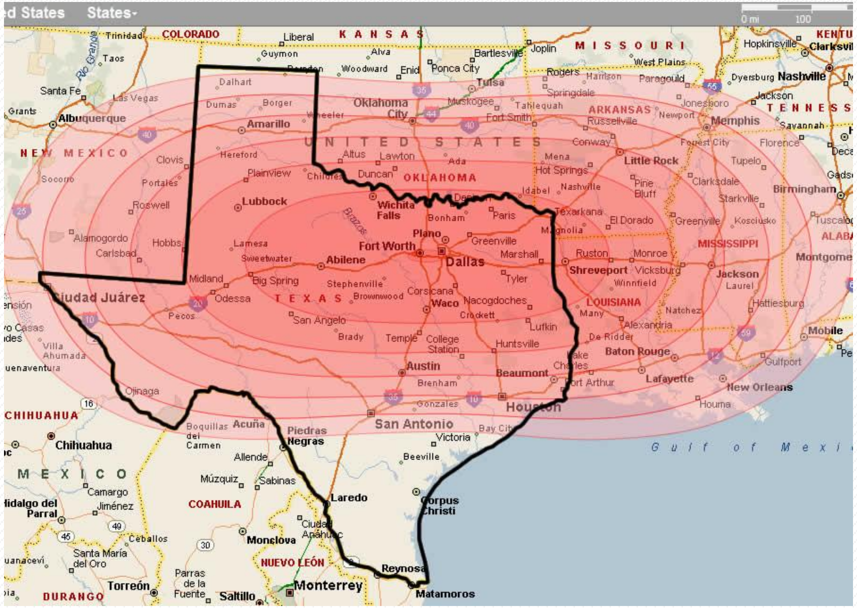


Mapped Propagation Patterns 2

Dipole ½-λ above ground

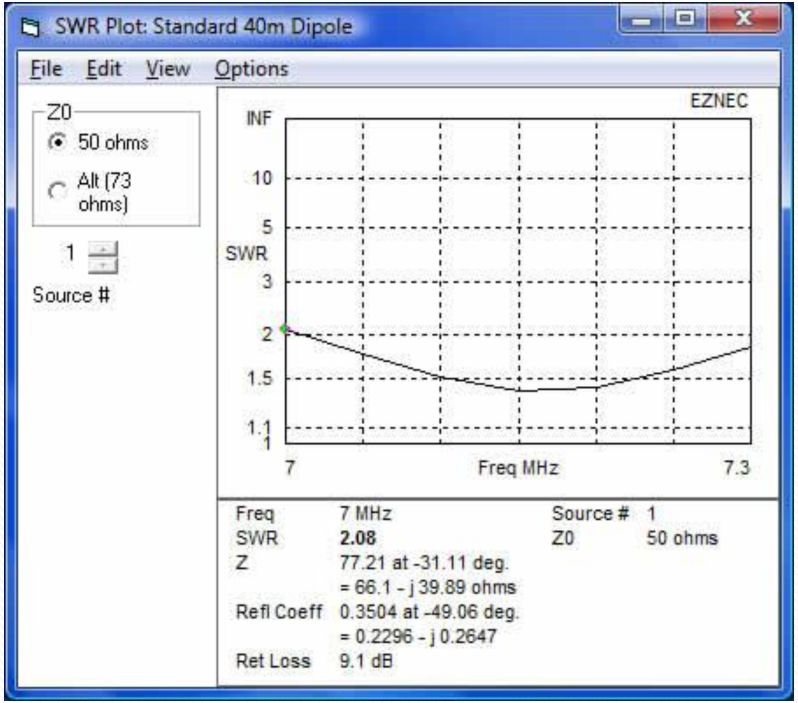


NVIS dipole



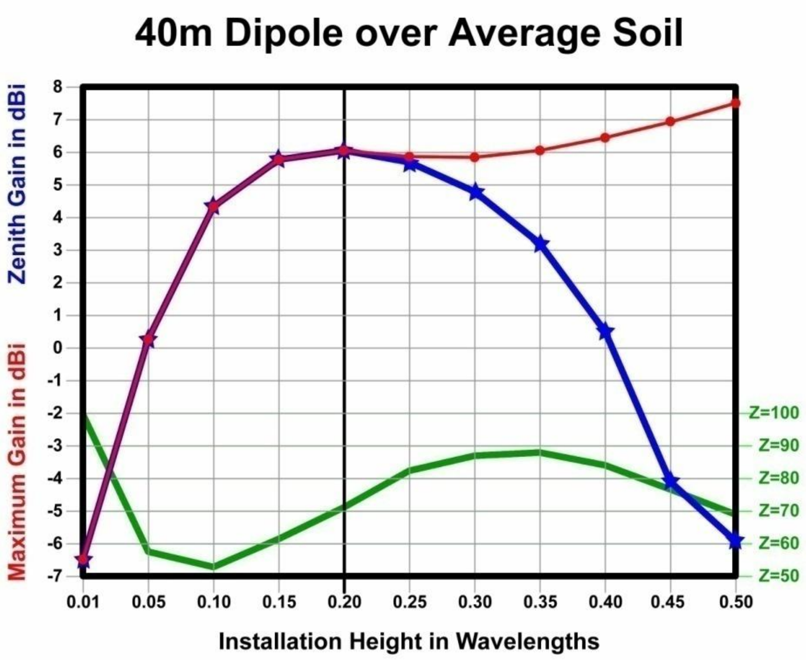
Bandwidth

We can define the antenna's bandwidth as the part of the band that can be tuned to 2:1 SWR or lower, preferably without the aid of a tuner.



Installation Height

- Installation height is very important
- The optimum height for NVIS reflects the highest Zenith Gain
- Notice how height affects the impedance



Ground (Soil) Quality

- As soil quality degrades, the optimum height of the NVIS increases
- As soil quality degrades, the broadside beamwidth increases in ratio to the endwire beamwidth

40m dipole

Soil Quality	Height	Max Gain	BS BW	EW BW	Feed R	Feed X
Very Good	0.175 λ	7.15 dBi	109.0	66.2	64.16	11.37
Average	0.195 λ	6.09 dBi	119.0	67.0	72.21	1.76
Very Poor	0.205 λ	4.86 dBi	129.0	67.8	73.90	-7.76

Debunking Reflector Myths

The myth states that a single wire (parasitic) reflector placed directly below the NVIS dipole will turn the dipole into a "cloud burning", 2-element HF yagi pointed straight upwards. The implication is that a parasitic reflector will greatly enhance an NVIS antenna.

Two Types of Reflectors

- **Parasitic Reflector:** a single wire reflector appx. 1.05 times the length of the driver element (dipole wires) and elevated 0.01-λ to 0.06-λ above the ground
- **Planar Reflector:** a series of 9 or more equal distanced, parallel wires centered beneath the NVIS antenna creating a rectangular screen that is 1.2-λ by 0.8-λ

Parasitic Reflector

- A 2-element yagi elevated at ½-λ above ground and pointing to the horizon can yield 3 dB gain
- A parasitic reflector near the ground and below an NVIS dipole or 1-λ loop only yields 0.2 dB to 0.7 dB gain, depending on soil quality, and it will decrease the bandwidth of the antenna by about 25%
- If placed below an NVIS Inverted Vee the bandwidth will decrease by 50% or more

Planar Reflector

- A planar reflector placed on the ground below an NVIS dipole, 1-λ loop, or Inverted Vee yields about 1 dB gain
- It has a negligible effect on the antenna's bandwidth
- It requires appx. 2800 feet of wire for 80m or 1476 feet for 40m
- It requires a space of 311 ft x 207 ft for 80m or 164 ft x 109 ft for 40m

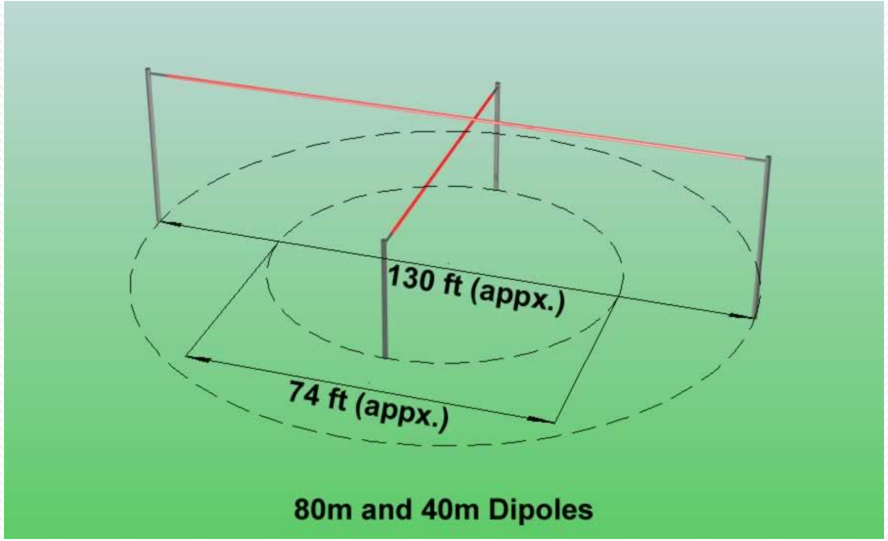
Fixed Station Antennas

In this section we look at the optimum installations of several types of NVIS antennas. By "fixed station" I mean a permanent location which affords us better opportunity to optimize our antenna than would a temporary field location. In the next section we will look at some practical field installations.

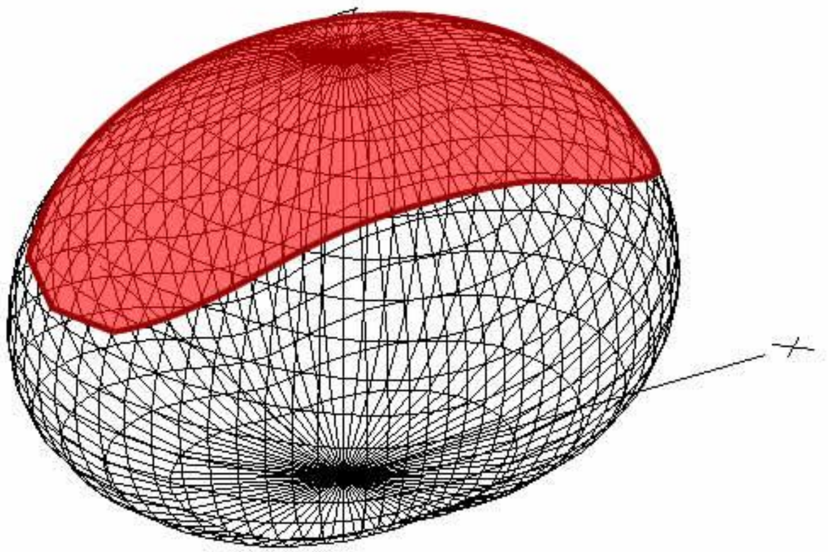
NOTE: All antennas in this presentation were modeled using AWG #14 copper stranded, insulated wire.

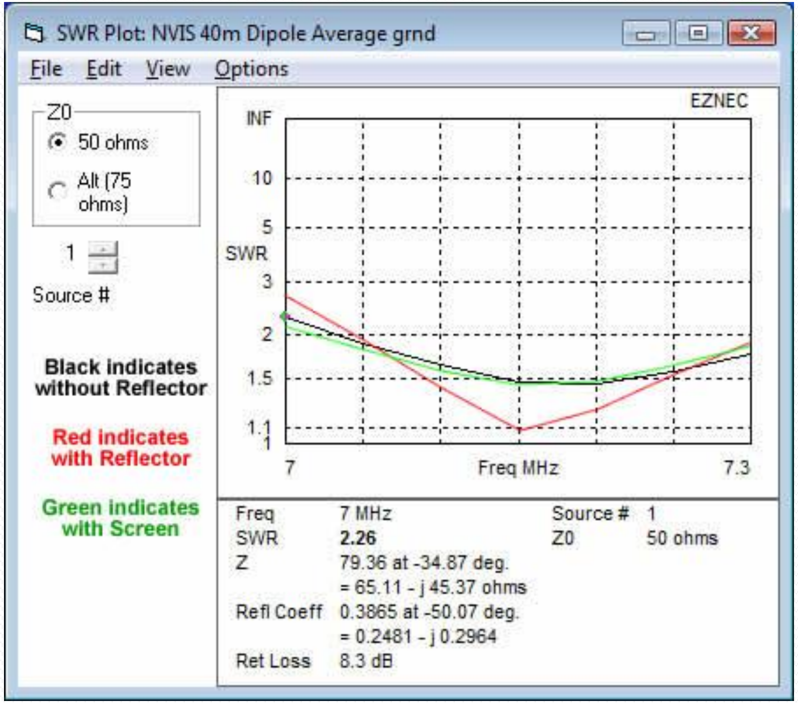
NVIS Dipoles (L=0.4806-λ)

80m Dipole Length = 0.4806-λ				40m Dipole Length = 0.4806-λ		
Soil	**Height**	**Gain**		**Soil**	**Height**	**Gain**
Very Good	0.165 λ 41.61 ft	7.40 dBi		Very Good	0.175 λ 23.91 ft	7.15 dBi
Avg.	0.185 λ 46.66 ft	6.42 dBi		Avg.	0.195 λ 26.64 ft	6.09 dBi
Very Poor	0.195 λ 49.18 ft	5.13 dBi		Very Poor	0.205 λ 28.00 ft	4.86 dBi



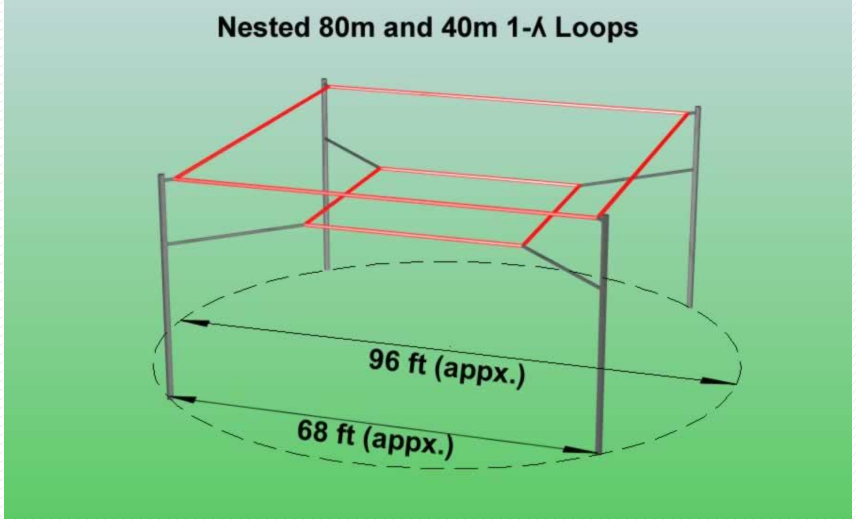
NVIS Dipoles



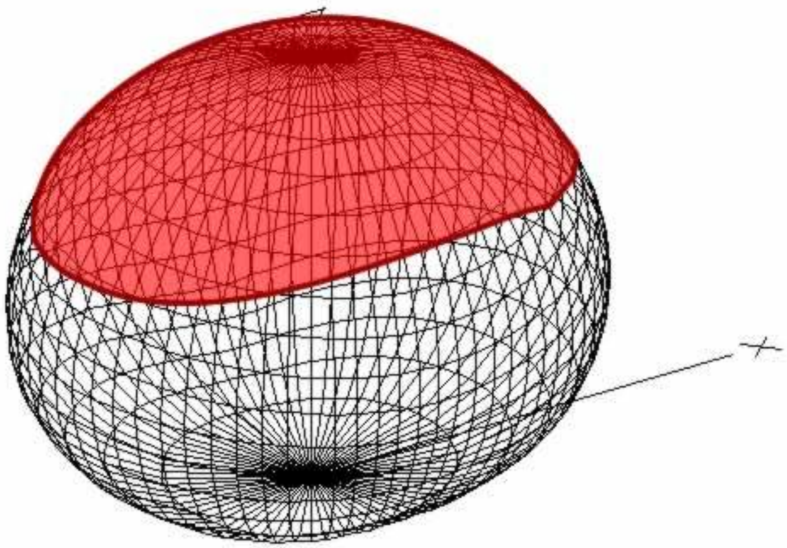


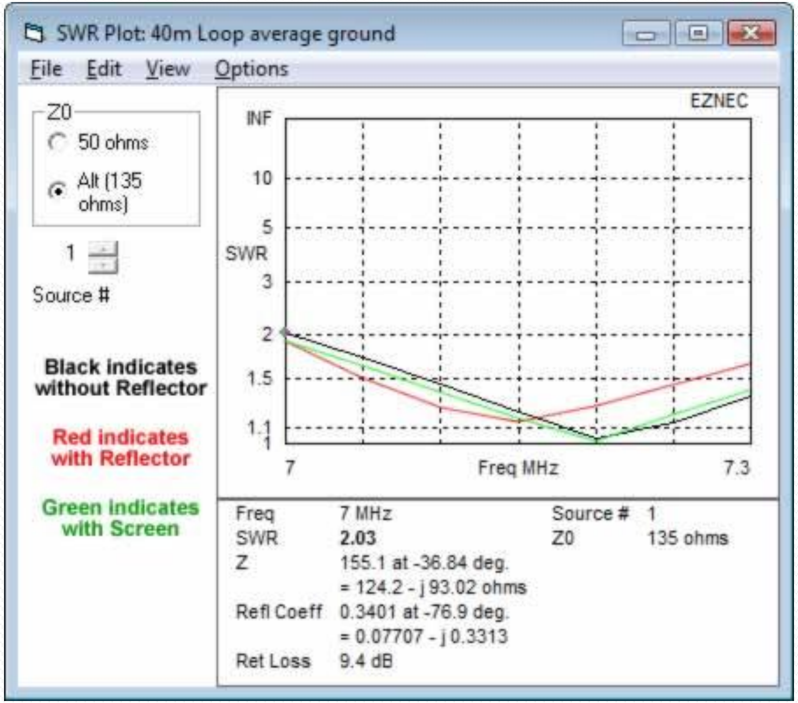
NVIS 1-λ Loops

80m Dipole Length = 1.0248-λ				40m Dipole Length = 1.0296-λ		
Soil	Height	Gain		Soil	Height	Gain
Very Good	0.165 λ 41.61 ft	7.96 dBi		Very Good	0.175 λ 23.91 ft	7.74 dBi
Avg.	0.185 λ 46.66 ft	7.04 dBi		Avg.	0.195 λ 26.64 ft	6.76 dBi
Very Poor	0.195 λ 49.18 ft	5.85 dBi		Very Poor	0.205 λ 28.00 ft	5.64 dBi



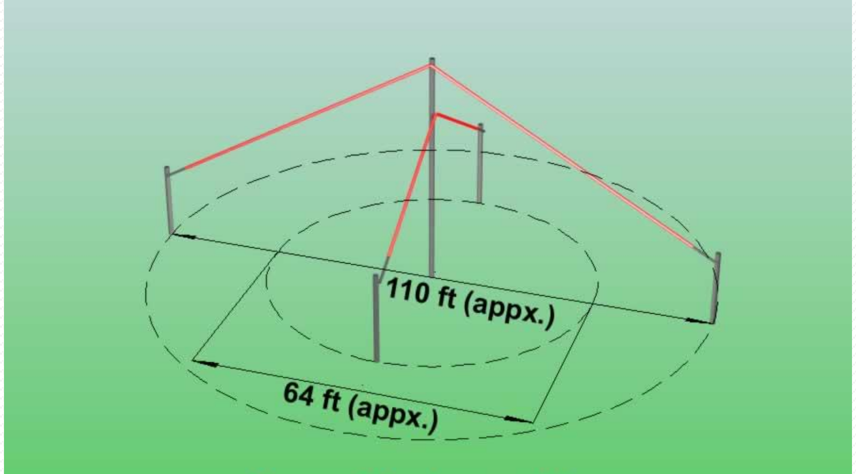
NVIS 1-λ Loops





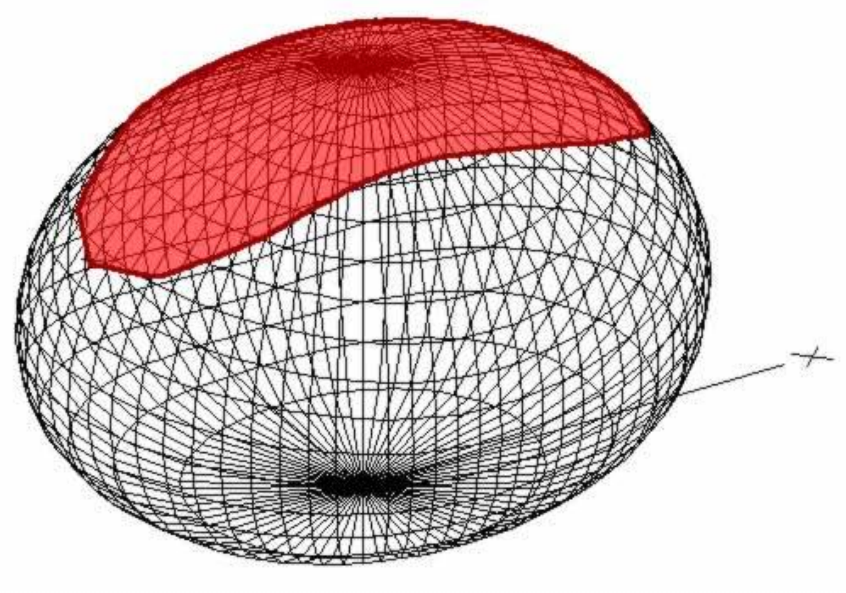
NVIS Inverted Vees

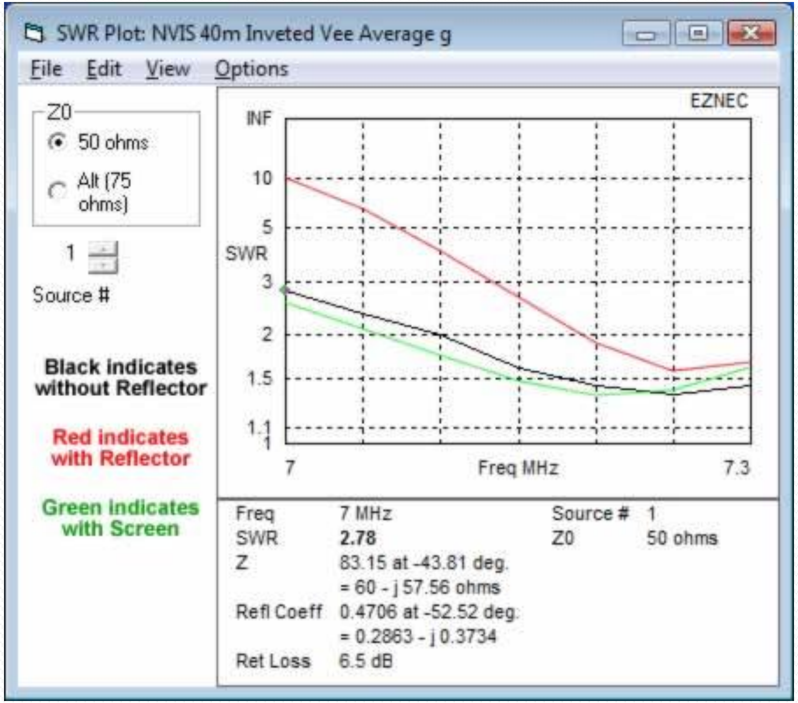
80m Inverted Vee Length = 0.4820-λ				40m Inverted Vee Length = 0.4820-λ		
Soil	Height	Gain		Soil	Height	Gain
Very Good	0.235 λ 59.27 ft	6.42 dBi		Very Good	0.235 λ 32.10 ft	6.19 dBi
Avg.	0.245 λ 61.79 ft	5.52 dBi		Avg.	0.255 λ 34.83 ft	5.24 dBi
Very Poor	0.255 λ 64.31 ft	4.33 dBi		Very Poor	0.255 λ 34.83 ft	4.11 dBi



80m and 40m Inverted Vees

NVIS Inverted Vees

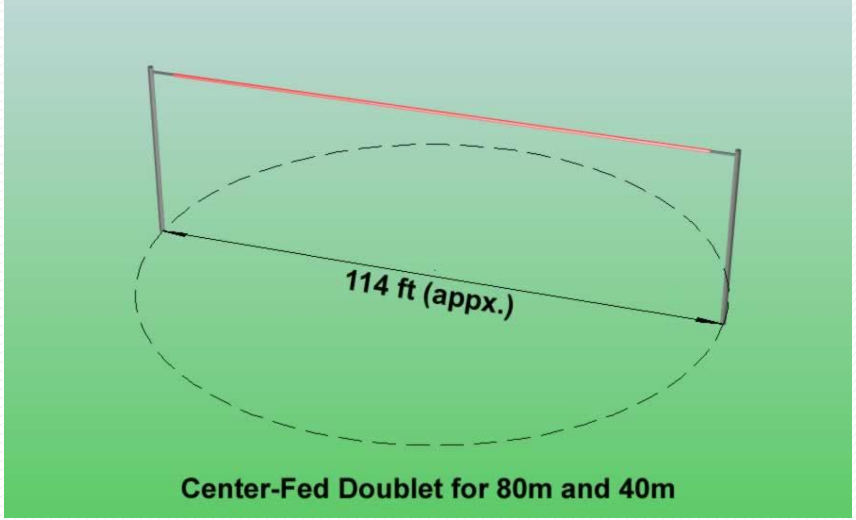




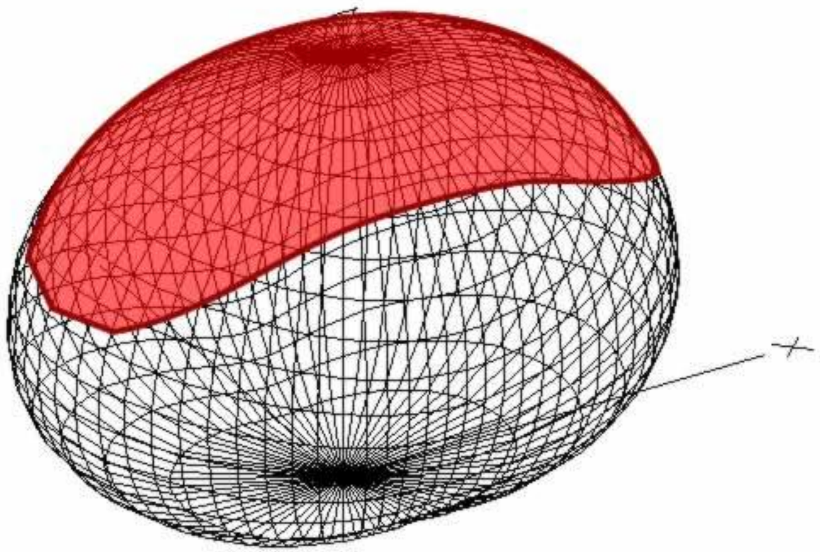
NVIS 104' 80m/40m Doublet

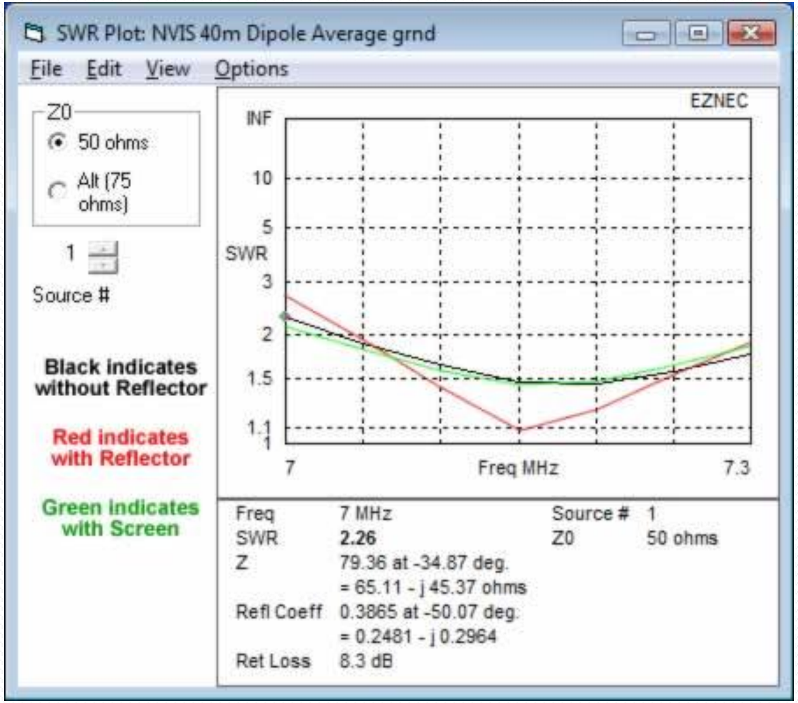
(with 33.5' 450 Ω ladderline)

		80m	60m	40m
Height	**Soil**	**Gain / R**	**Gain / R**	**Gain / R**
35 feet	Very Good	7.16 dBi 29.01 Ω	7.40 dBi 477.50 Ω	7.14 dBi 55.76 Ω
35 feet	Avg.	5.90 dBi 34.20 Ω	6.43 dBi 537.10 Ω	6.34 dBi 54.92 Ω
35 feet	Very Poor	4.40 dBi 39.00 Ω	5.15 dBi 610.00 Ω	5.30 dBi 53.57 Ω



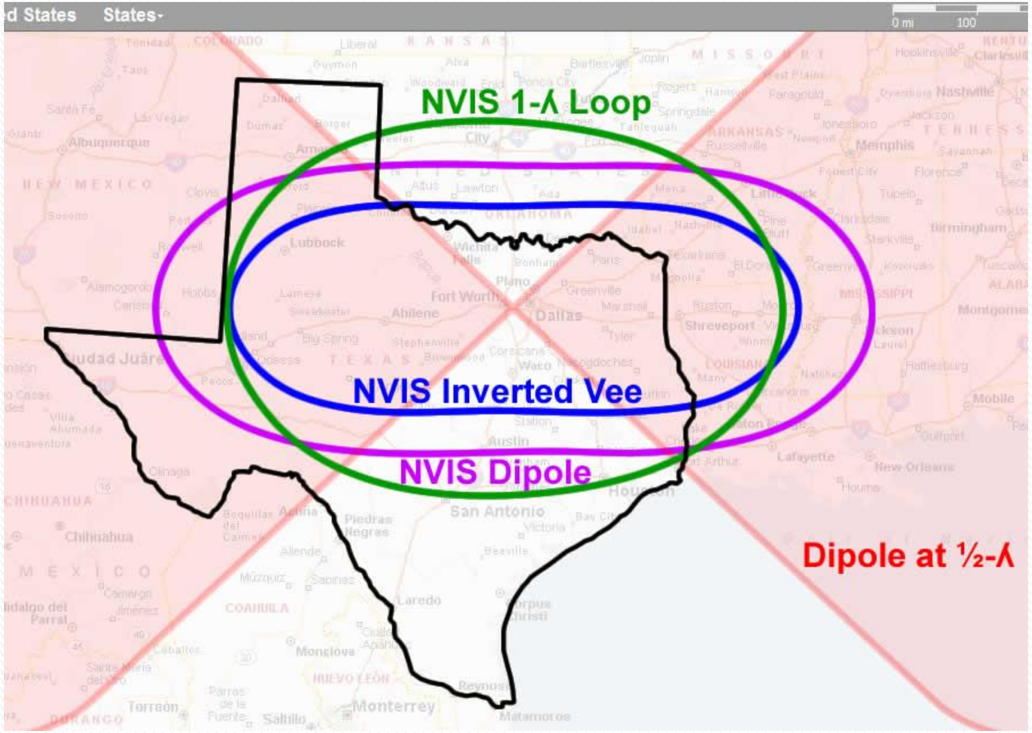
NVIS 104’ 80m/40m Doublet





Comparison of radiation patterns

NOTE: These radiation patterns reflect signal coverage at 4.59 dBi for each antenna shown in order to better compare them to the beamwidth of the dipole installed at ½-λ, which has a beamwidth of 7.59 to 4.59 dBi.



Field Station Antennas

In this section we look at less than the optimum, but practical, installations of a few types of NVIS antennas at temporary field locations.

NOTE: All antennas in this presentation were modeled using AWG #14 copper stranded, insulated wire.

Dipoles

Practical Field Installation					Optimum Fixed Installation				
80m (3.9 MHz) installed at 35 feet					**80m (3.9 MHz) installed at optimum height**				
Soil	**Zen Gain**	**BS BW**	**EW BW**		**Soil**	**Height**	**Zen Gain**	**BS BW**	**EW BW**
Very Good	7.30 dBi	101.6	64.4		Very Good	41.61 ft	7.40 dBi	105.6	65.4
Average	6.07 dBi	106.8	65.2		Average	46.66 ft	6.42 dBi	115.0	67.0
Very Poor	4.59 dBi	115.8	66.8		Very Poor	49.18 ft	5.13 dBi	126.4	68.2
40m (7.2 MHz) installed at 25 feet					**40m (7.2 MHz) installed at optimum height**				
Soil	**Zen Gain**	**BS BW**	**EW BW**		**Soil**	**Height**	**Zen Gain**	**BS BW**	**EW BW**
Very Good	7.14 dBi	110.4	66.7		Very Good	23.91 ft	7.15 dBi	109.0	66.2
Average	6.07 dBi	116.4	66.4		Average	26.64 ft	6.09 dBi	118.8	67.0
Very Poor	4.78 dBi	124.8	67.0		Very Poor	28.00 ft	4.86 dBi	129.0	67.8

1-λ Loops

Practical Field Installation					Optimum Fixed Installation				
80m (3.9 MHz) installed at 35 feet					**80m (3.9 MHz) installed at optimum height**				
Soil	**Zen Gain**	**BS BW**	**EW BW**		**Soil**	**Height**	**Zen Gain**	**BS BW**	**EW BW**
Very Good	7.87 dBi	81.8	67.8		Very Good	41.61 ft	7.96 dBi	84.7	69.0
Average	6.70 dBi	85.3	68.6		Average	46.66 ft	7.04 dBi	92.0	70.8
Very Poor	5.32 dBi	91.8	70.8		Very Poor	49.18 ft	5.85 dBi	101.8	72.2
40m (7.2 MHz) installed at 25 feet					**40m (7.2 MHz) installed at optimum height**				
Soil	**Zen Gain**	**BS BW**	**EW BW**		**Soil**	**Height**	**Zen Gain**	**BS BW**	**EW BW**
Very Good	7.73 dBi	88.2	70.4		Very Good	23.91 ft	7.74 dBi	87.0	69.8
Average	6.74 dBi	92.6	70.0		Average	26.64 ft	6.76 dBi	95.0	70.8
Very Poor	5.57 dBi	99.1	70.8		Very Poor	28.00 ft	5.64 dBi	104.0	71.8

Inverted Vees with 30° Angle

Practical Field Installation					Optimum Fixed Installation				
80m (3.9 MHz) installed at 45 feet					**80m (3.9 MHz) installed at optimum height**				
Soil	**Zen Gain**	**BS BW**	**EW BW**		**Soil**	**Height**	**Zen Gain**	**BS BW**	**EW BW**
Very Good	5.93 dBi	101.8	81.4		Very Good	59.27 ft	6.42 dBi	111.6	78.5
Average	4.59 dBi	107.2	80.4		Average	64.31 ft	5.52 dBi	119.6	77.4
Very Poor	3.14 dBi	116.4	79.8		Very Poor	64.31 ft	4.33 dBi	130.4	76.4
40m (7.2 MHz) installed at 35 feet					**40m (7.2 MHz) installed at optimum height**				
Soil	**Zen Gain**	**BS BW**	**EW BW**		**Soil**	**Height**	**Zen Gain**	**BS BW**	**EW BW**
Very Good	6.17 dBi	117.8	78.8		Very Good	32.10 ft	6.19 dBi	113.2	78.2
Average	5.24 dBi	123.8	76.8		Average	34.83 ft	5.24 dBi	123.4	76.8
Very Poor	4.11 dBi	131.2	75.6		Very Poor	34.83 ft	4.11 dBi	131.0	75.6

End of Presentation