Antenna Performance
Vertical vs Horizontal Antennas

Ken Larson KJ6RZ
www.skywave-radio.org
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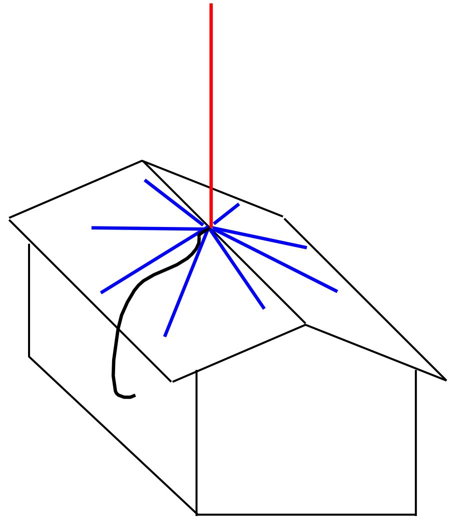
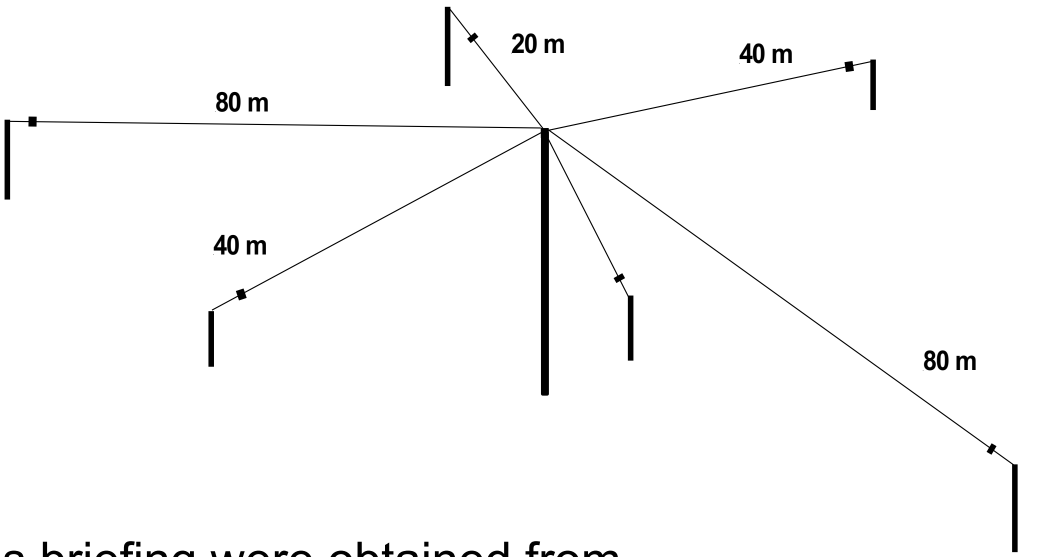
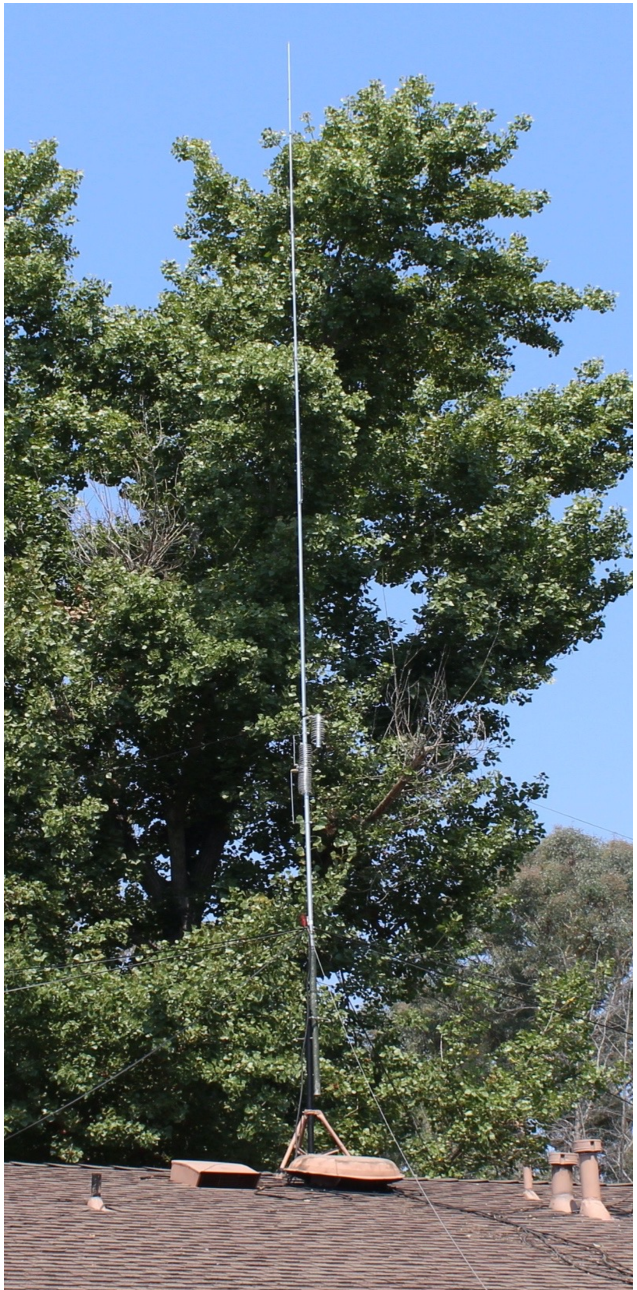
Introduction





- The results presented in this briefing were obtained from
  - Available literature, and
  - Detailed antenna tests
- Tests were performed on 80, 40, and 20 meters using
  - A roof mounted 1/4 wavelength vertical antenna, and
  - A set of three Inverted V antennas

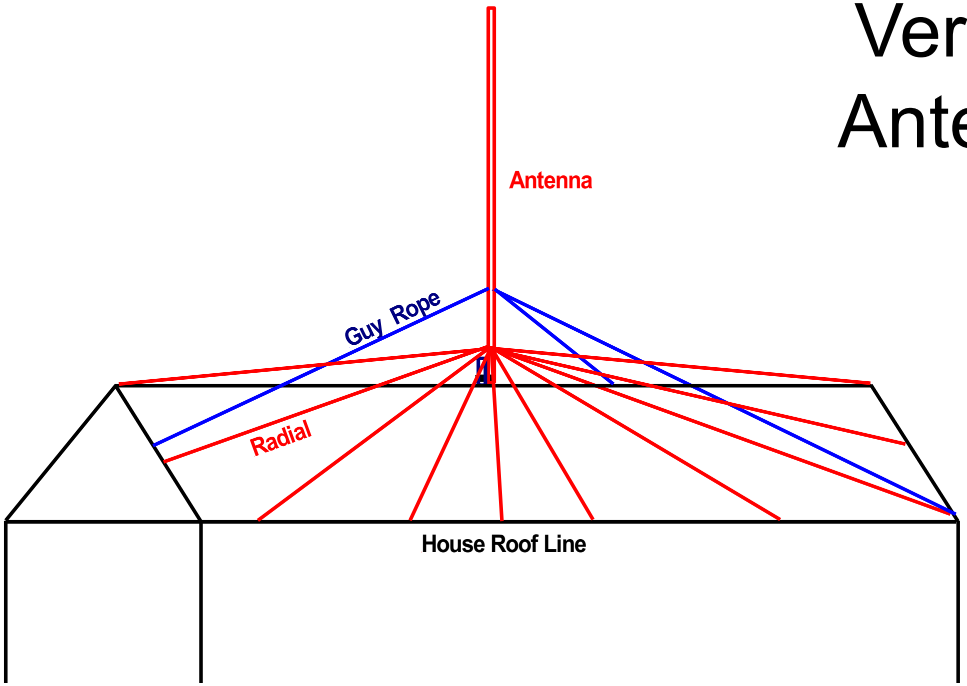
Antennas Used In Tests



< Vertical

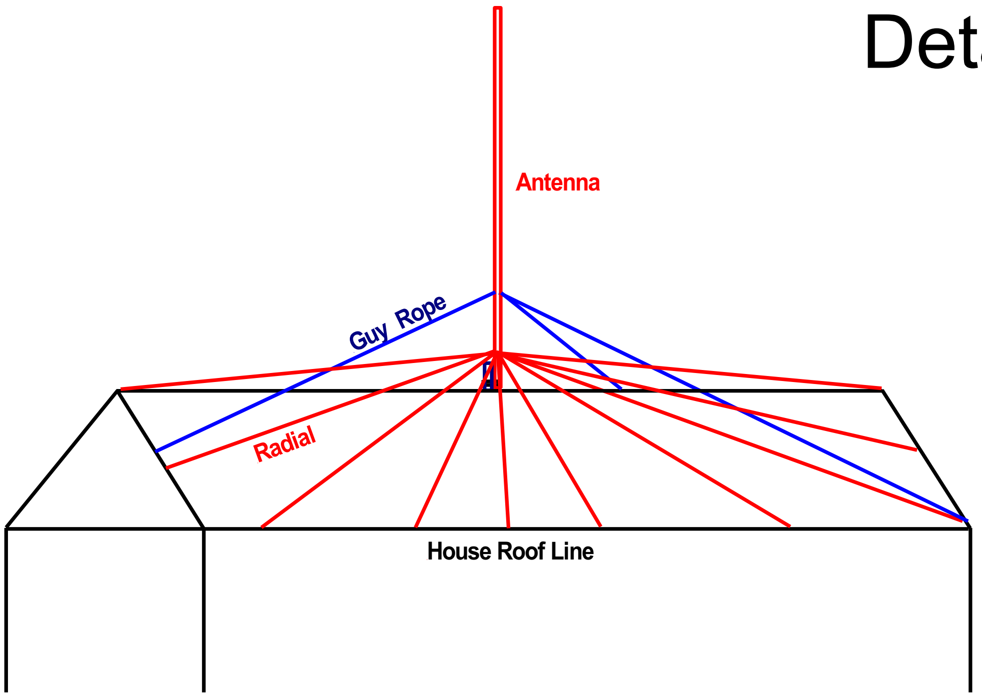
Inverted V >

Vertical Antenna



- A roof mounted vertical antenna, with radials, was constructed specifically for this test
- A roof mounted vertical was used since there was not room in my yard for a quality ground radial system
- Plus, popular half wave no radial verticals are compromise antennas with lower performance than full size 1/4 wave vertical antennas with radials
- Small variations in performance were important

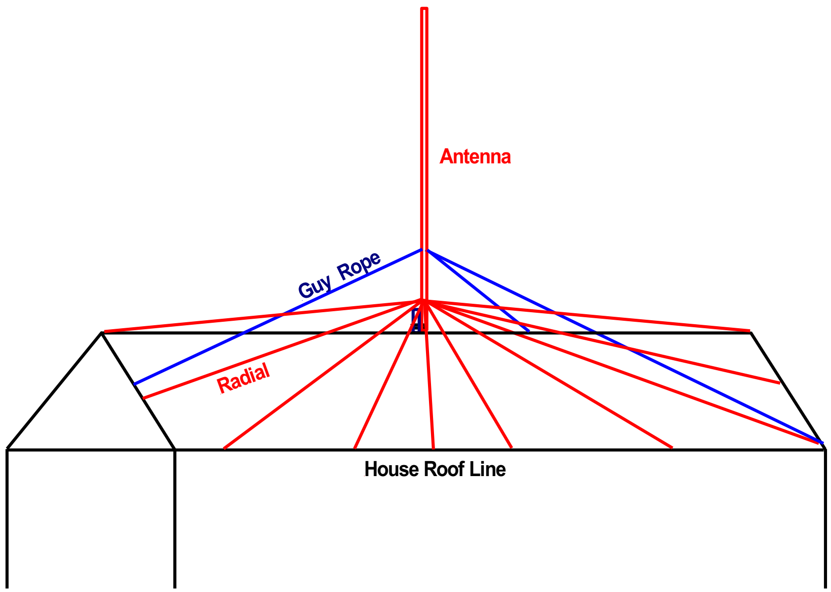
Vertical Antenna Details



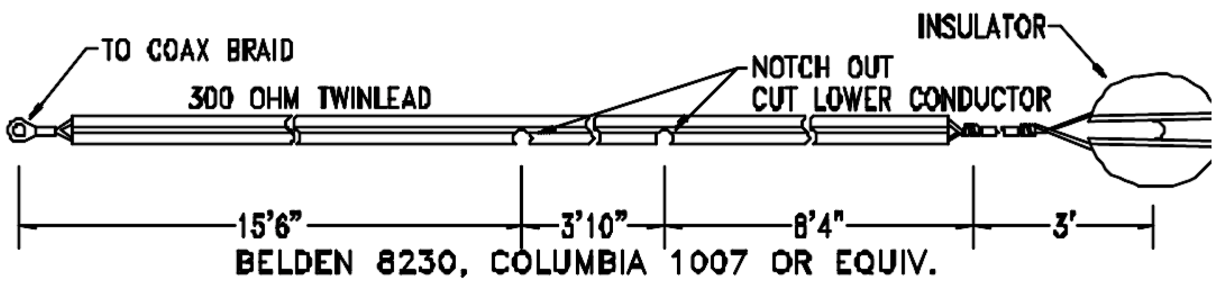
Ground Mounted HF6V

- A Butternut HF6V vertical antenna was selected
- Antenna covers 80, 40, 30, 20, 15 and 10 meters

Elevated Radial Vertical Antenna System



- A roof mounted 1/4 wavelength vertical antenna is a resonant elevated radial antenna system
- All radials must be identical in length and 1/4 wavelength long for each frequency band
- A total of 16 multiband tuned Butternut radials (STR-II) were evenly spaced around the roof



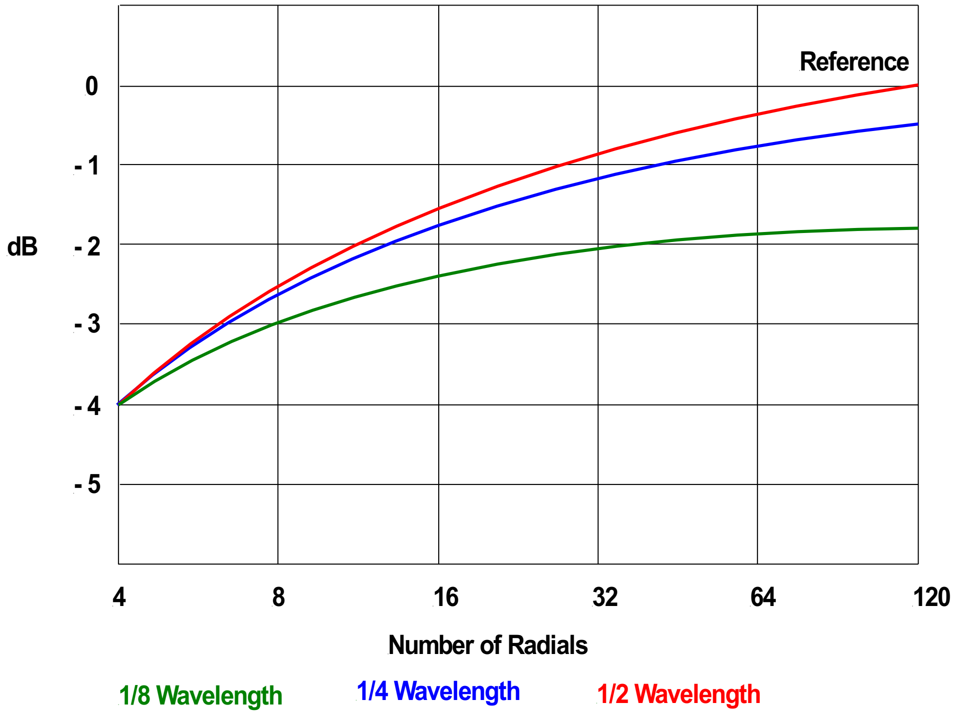
STR-II Radial

40 / 15 meters

20 meters

10 meters

80 Meter Radials



This chart is for radials buried in the ground, but may provide insight for elevated radials provided that there are a sufficient number of elevated radials

- I very much wanted to test on 80 meters but my yard was not large enough for 80 meter radials, so I initially gave up (reluctantly) on 80 meters as a test band
- However, when I tested the vertical on 80 meters it worked just fine
- My guess is that the sixteen 1/4 wavelength 40 meters radials operated as 1/8 wavelength radials on 80 meters, not resonant but providing a ground plane
- The above chart for ground radials suggests that while the vertical was working on 80 meters, I was probably experience some loss maybe 2.5 – 3 db loss

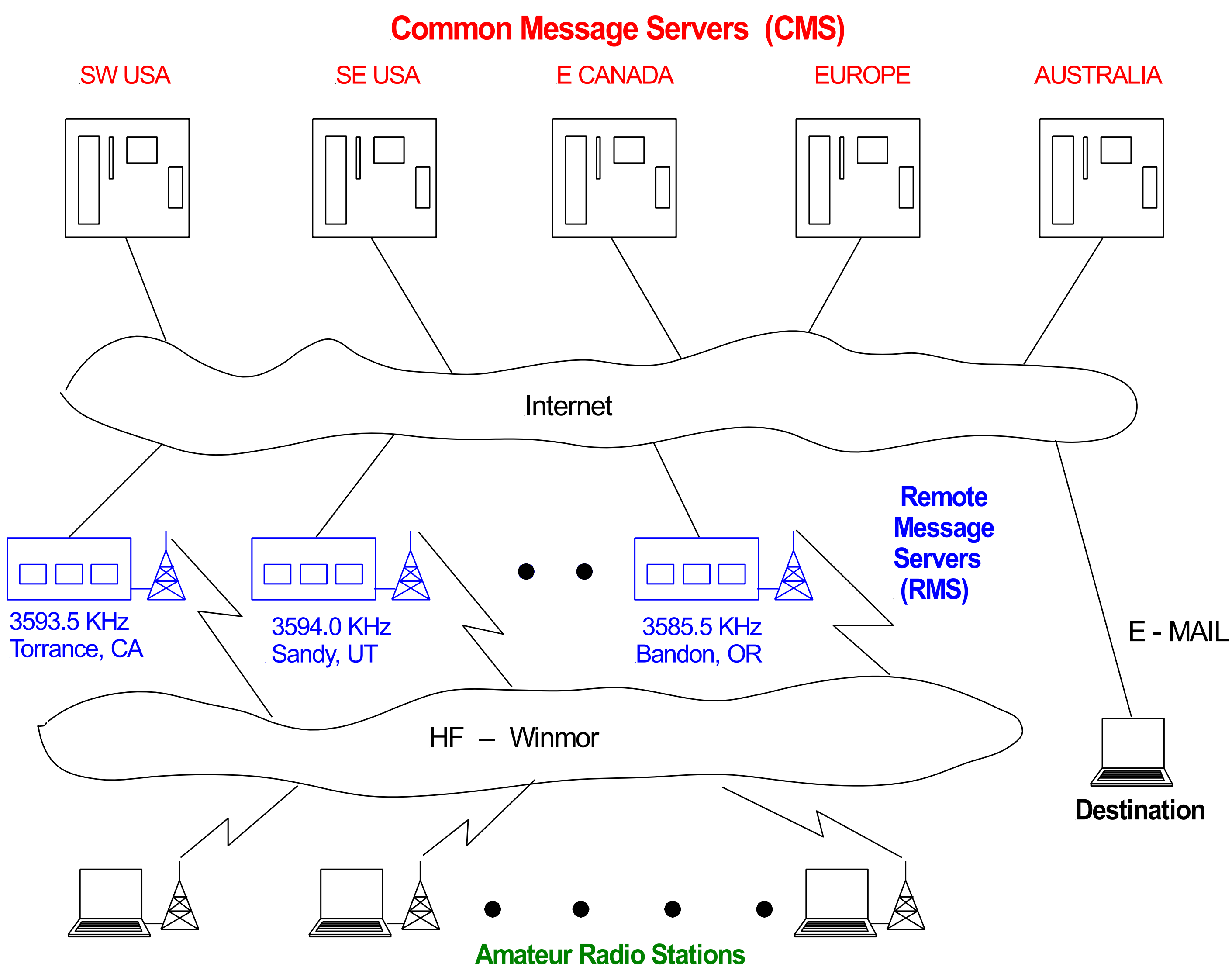
Inverted V Antenna System

- As set of 3 separate Inverted V antennas were used
- In the picture, 20 meter antenna is at the top, 80 meter in middle and 40 meter antenna at the bottom
- Antennas mounted about 32 feet above ground level
- Elevation above ground
  - 80 meter 1/8 wavelength
  - 40 meter 1/4 wavelength
  - 20 meter 1/2 wavelength
- Each antenna used a current balun to prevent current from flowing down the outside of the coax perverting antenna patterns
- Each antenna feed by its own coax cable

Conducting The Tests

- Tests were conducted with Winlink Remote Message Server (RMS) stations
- RMS stations were used since:
  - There are a large number of them located throughout the United States
  - Each RMS station is at a known location
  - Each RMS station operates continuously 24 hours a day, 7 days a week
- A fixed length message was transmitted to an RMS station using the vertical
- The time required to complete the transmission was reported by RMS station
  - Typically 30 to 60 seconds for a successful message transmission
  - Poor transmission ~ 2 minutes
  - Failed transmission > 3 minutes
- Transmission repeated using Inverted V antenna
- Large number of tests performed both night and day with a large number of different RMS stations

The Winlink Network

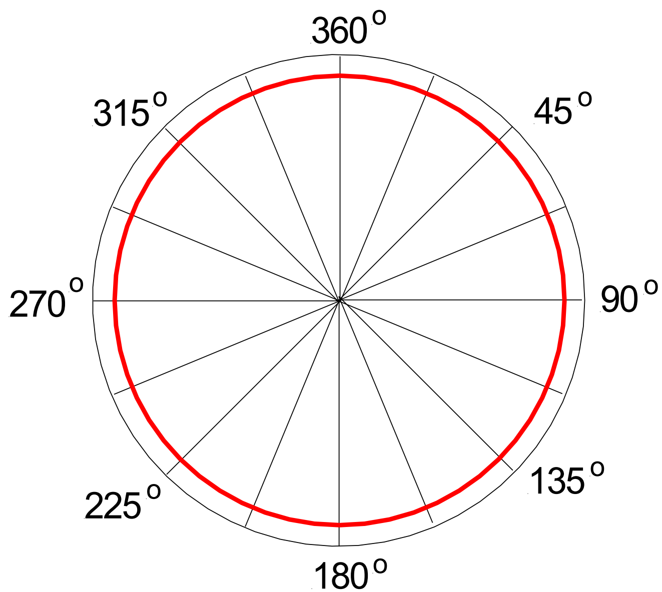


Initial Failure – Then Success

- Initially transmissions were performed at 100 watts
- At this power level the length of time to receive a message, as reported by each RMS station and including error retransmissions, was the same for both the vertical and Inverted V antennas
- There was no difference between the two types of antennas
- The transmit power level was dropped
- Finally, differences between the antennas began to appear at power levels of 8 to 10 watts.
- From that point on all tests were performed at 8 to 10 watts, even with Hawaii on 80 meters late at night
- Some of the test results were unexpected, but on careful reading were occasionally alluded to in the literature
- A new understanding of antenna elevation patterns was acquired

Vertical Antenna Radiation Patterns

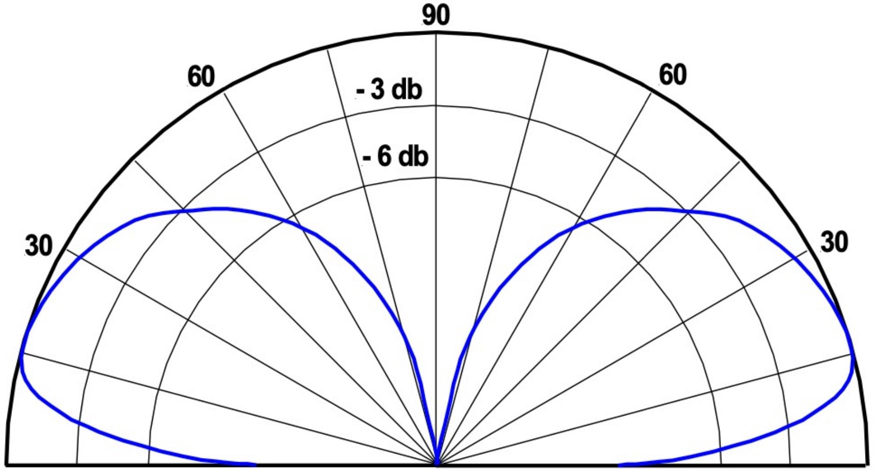
Vertical Antenna Horizontal Radiation Pattern



Horizontal Radiation Pattern
Vertical Antenna

- The horizontal radiation pattern for a vertical antenna is simply a circle
- A vertical antenna is omni directional, that is it radiates equally in all directions

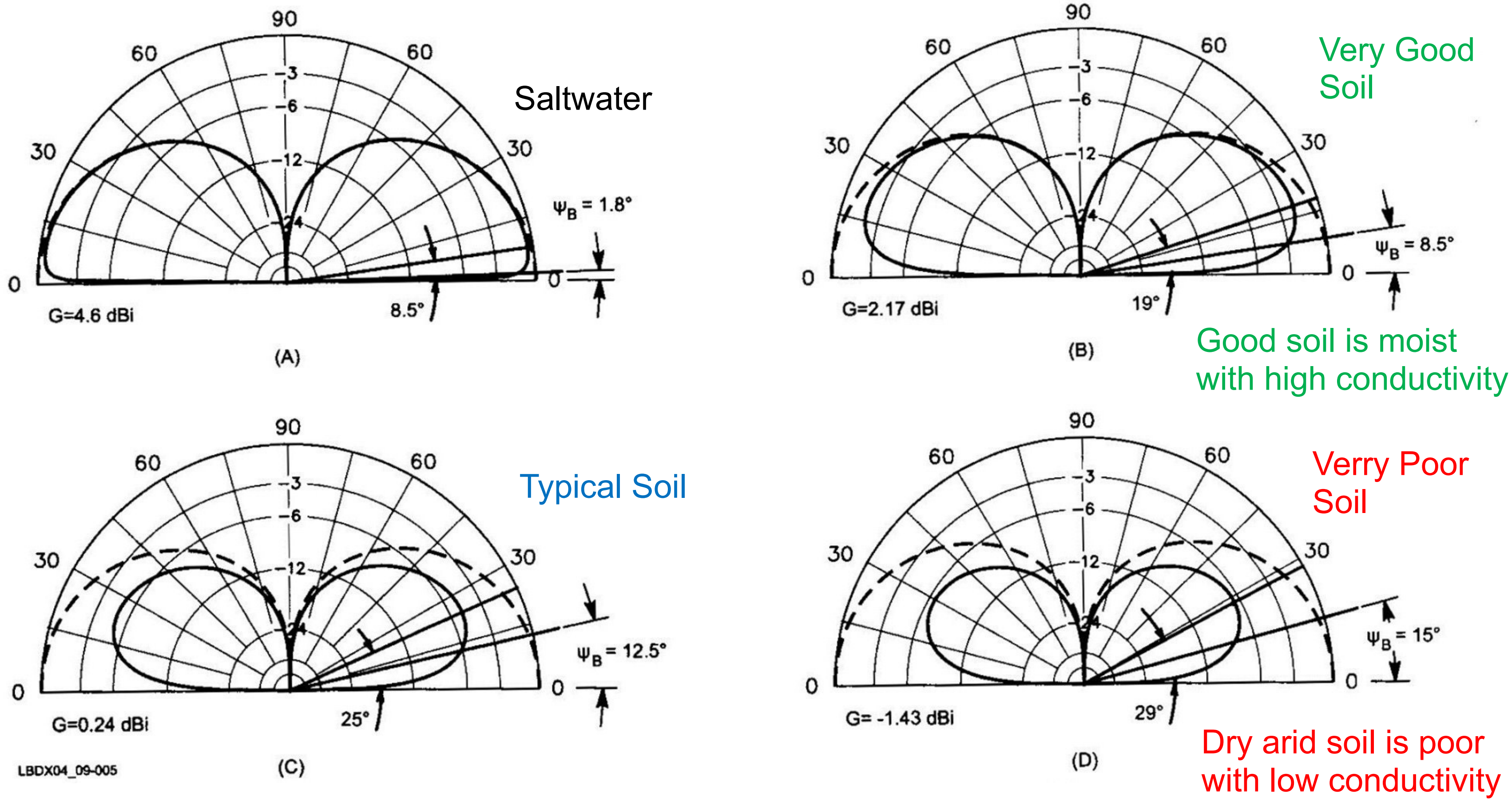
Vertical Antennas Are Not Lasers



1/4 Wave Vertical Antenna Over Very Good Ground

- In fact,
- A vertical antennas is a relatively crude device illuminating large areas of the sky with its radiated energy
- The drawing shows the elevation pattern for a 1/4 wavelength vertical antenna over very good soil

Elevation Patterns For a Vertical Antenna

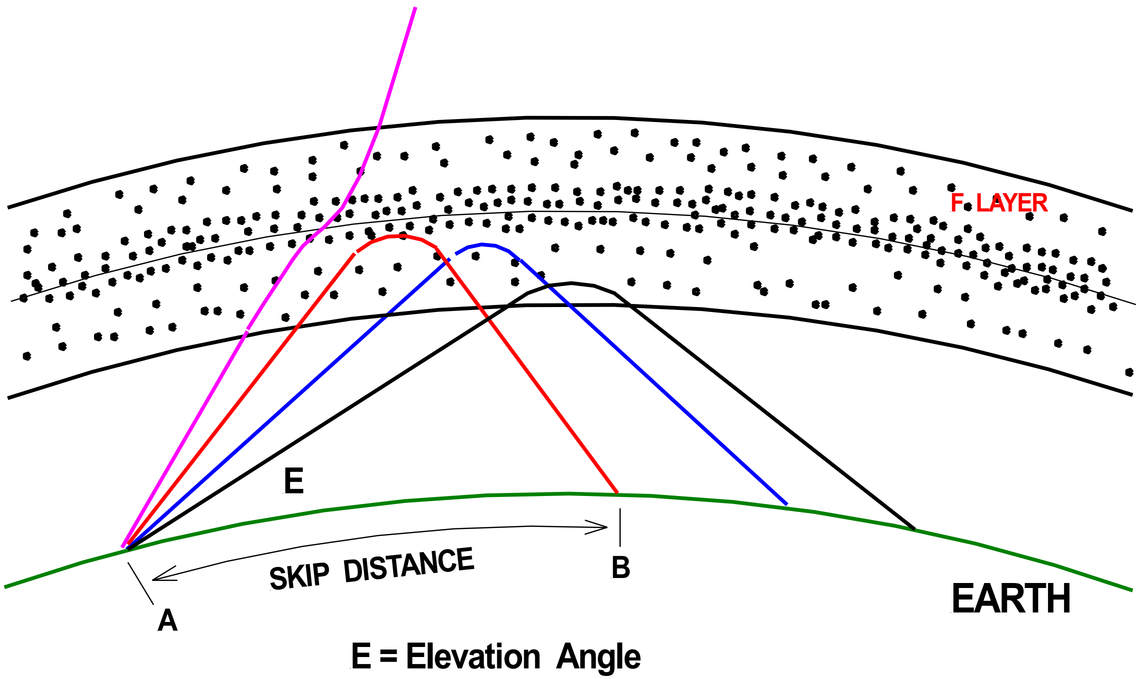


- The elevation pattern for a vertical antenna depends on ground conditions
- Performance of vertical antennas is best over moist highly conductivity soil

Soil Condition Ratings

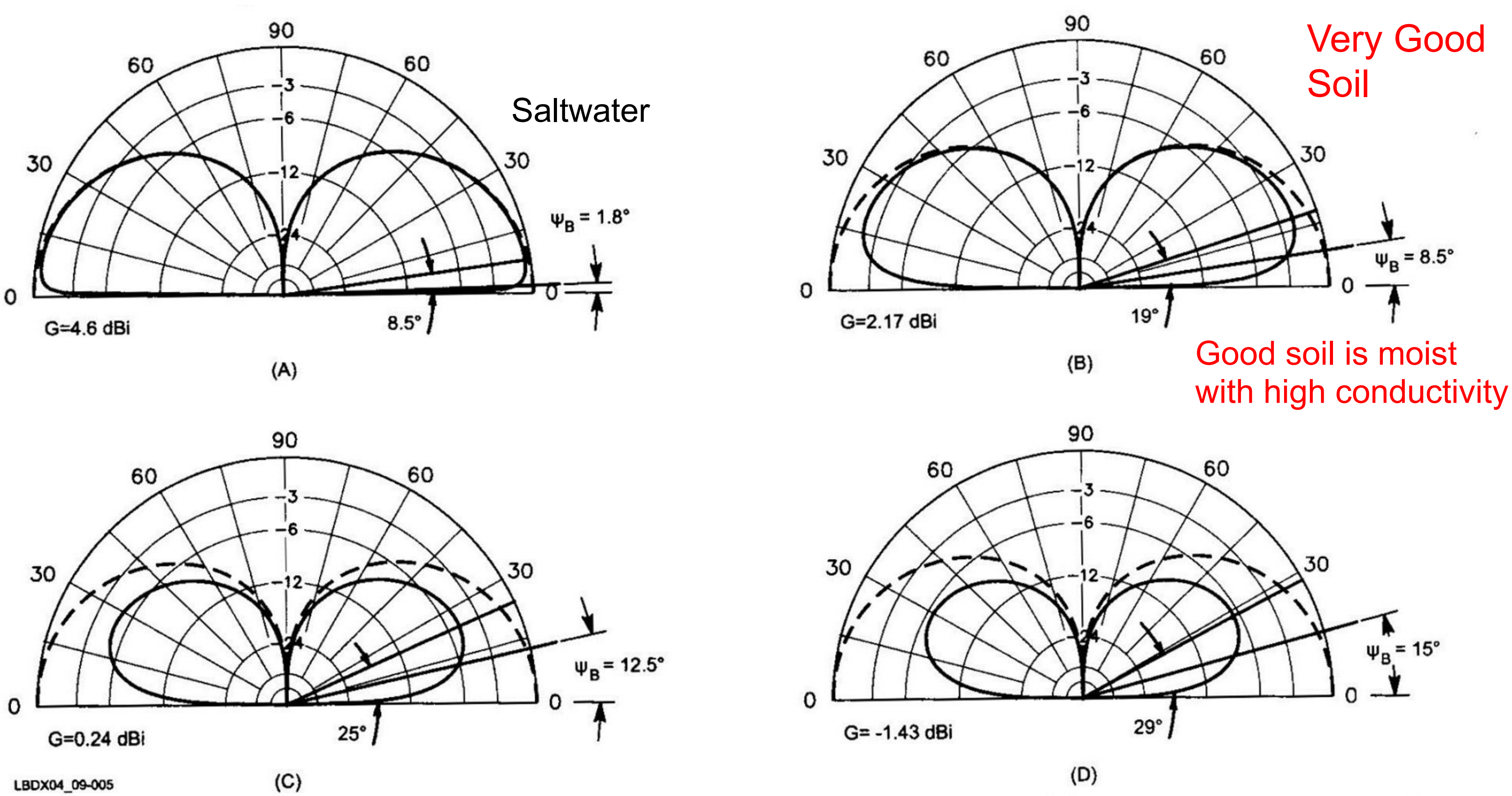
Quality	Soil Type	Dielectric Constant	Conduct-ivity (S/m)
Excellent	Salt water	81	5.0
Very Good	Pastoral, flat to low hills, rich soil (Dallas, TX to Lincoln, NE area)	20	0.0303
Good	Pastoral, flat to hills, rich soil, forestation OH, IL, LA, + non mountain MD, PA, NY	13 - 14	0.006 – 0.01
Average	Pastoral, medium hills, forestation, heavy clay typical of central VA	13	0.005
Poor	Rocky soil, mountainous, + desert areas	10 - 14	0.002
Very Poor	Cities and industrial areas	5	0.001
Extremely Poor	Cities, heavy industrial areas, high buildings	3	0.001

Antenna Elevation Angle



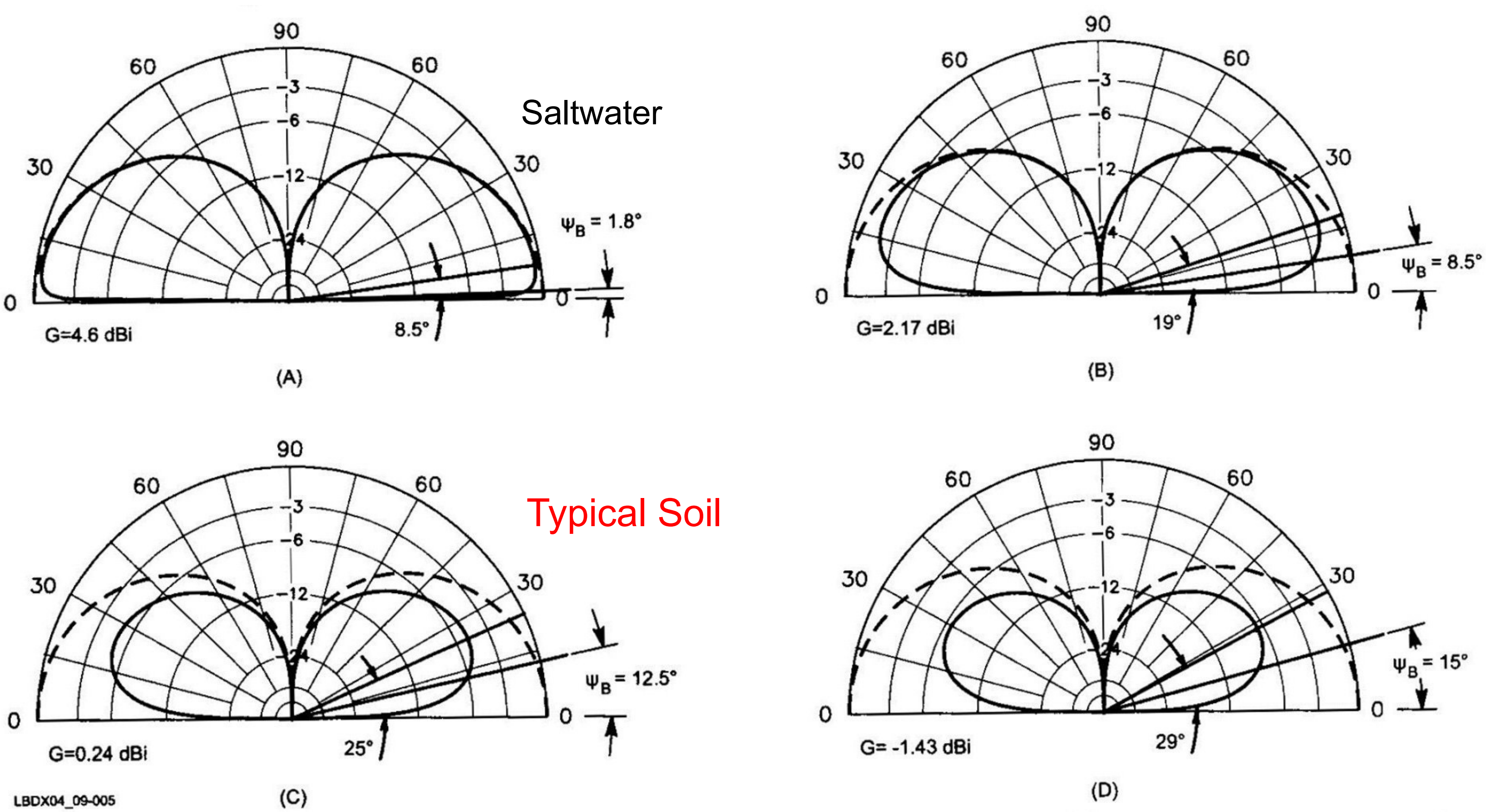
- Signals radiated at low elevation angles propagate long distances (good DX)
- Signals travel shorter distances as the elevation angle E increases
- A signal will pass through the ionosphere and be lost to outer space if the elevation angle is too great
- For good DX we want antennas that radiate at low elevation angles

Elevation Pattern Over Very Good Soil



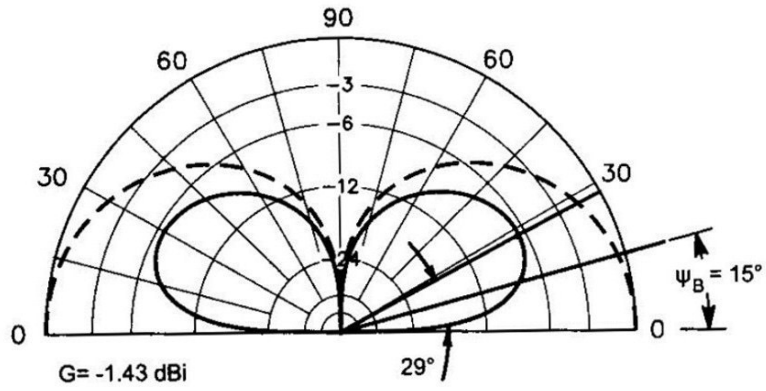
- A vertical is an excellent low angle DX antenna over very good soil
- Peak signal elevation angle around 19°
- Very little loss compared to radiation near saltwater

Elevation Pattern Over Typical Soil



- A vertical is an OK DX antenna over typical soil
- Elevation angle increases to around 25°
- Antenna begins to experience increasing signal loss, between 5 to 6 db

Vertical Antenna Elevation Pattern - Poor Soil

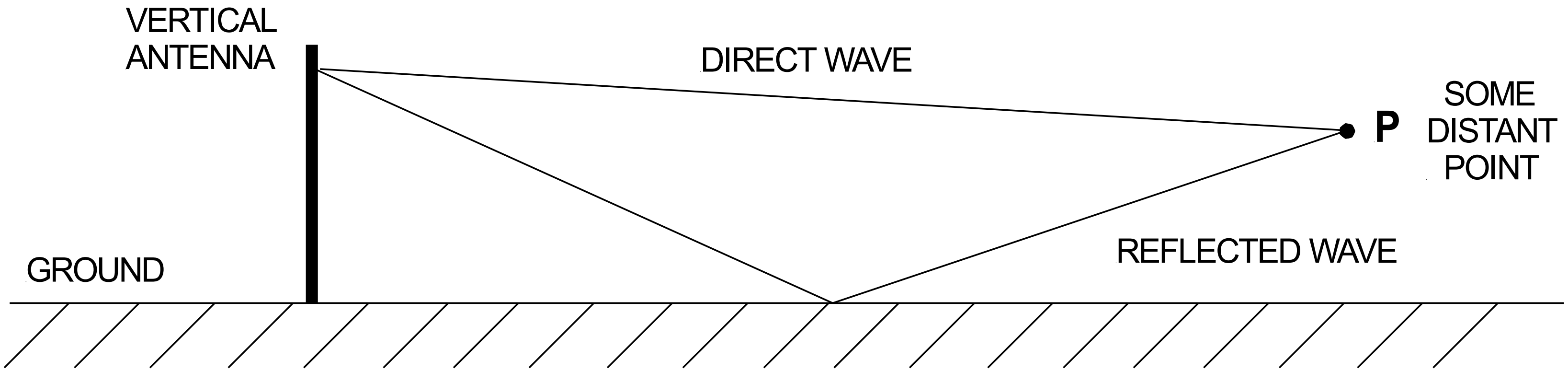


The solid curve represents the vertical radiation pattern over poor soil

Loss is over 6 db

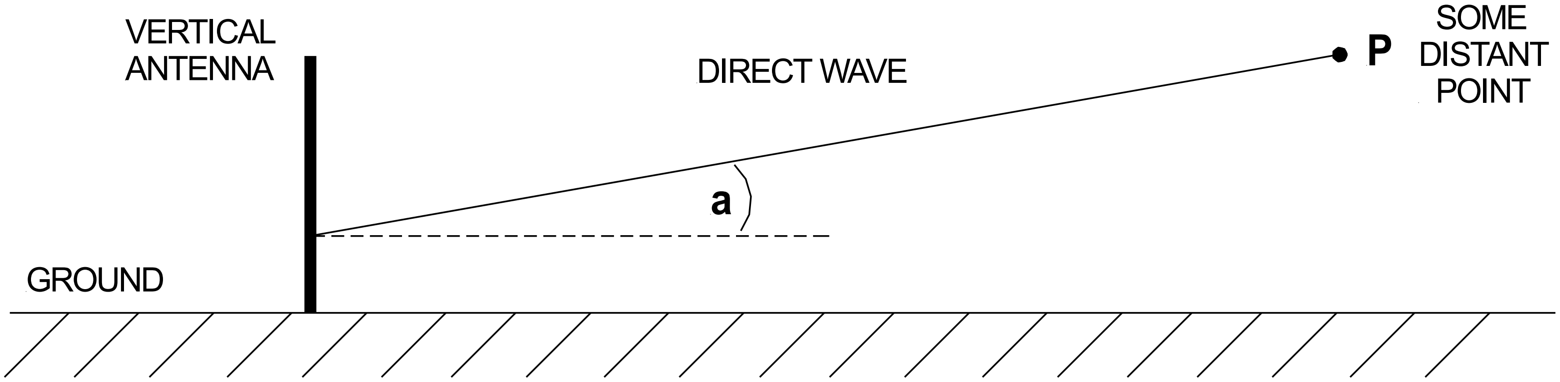
- Vertical antennas experience serious signal loss over poor soil (> 6 db)
- There is nothing you can do to solve this problem
- Radials make a vertical antenna work
- But, the soil being talked about here is that
  - Further out in your yard beyond the radials
  - In you neighbor's yard
  - In you neighbor's neighbor's yard, etc.
- Soil conditions in residential areas are particularly bad due to all of the houses, streets, sidewalks, driveways, etc.

Radiated Signal Strength



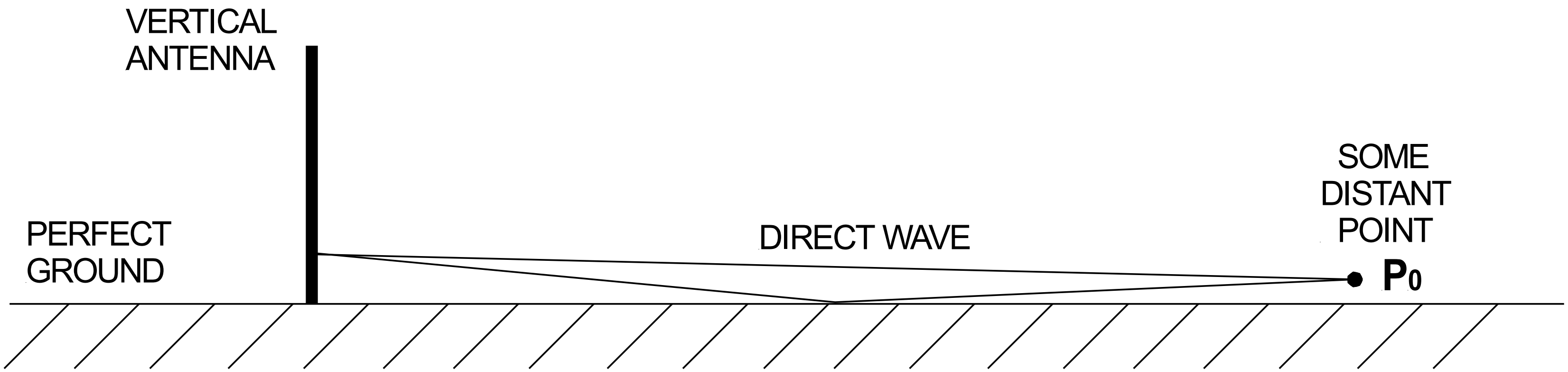
- The strength of the transmitted signal at a point P is the sum of the Direct Wave and the Reflected Wave
- The two waves add together if they are in phase, and subtract if they are out of phase
- The phase of the direct wave depends only on its travel time to Point P
- The phase of the reflected wave depends on both its travel time to Point P AND the phase shift incurred during reflection

Elevation Angle



- Elevation angle is the angle “a” of the direct wave relative to a horizontal line

Signal Strength at Low Elevation Angle

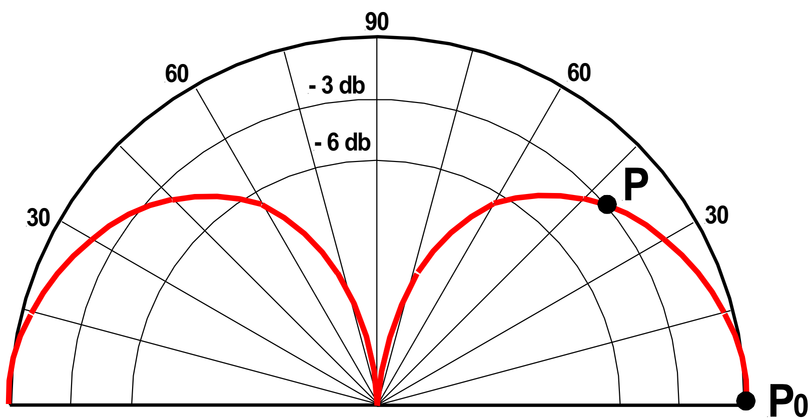


- No reflection phase shift occurs for a vertically polarized signal if the ground is a perfect conducting surface (the ideal situation)

- For a very low (near 0 deg) elevation angle, the time of travel to Point P_0 is approximately the same for both the direct and the reflected waves

- Under these conditions, the direct and reflected waves add together producing maximum signal strength at P_0 .

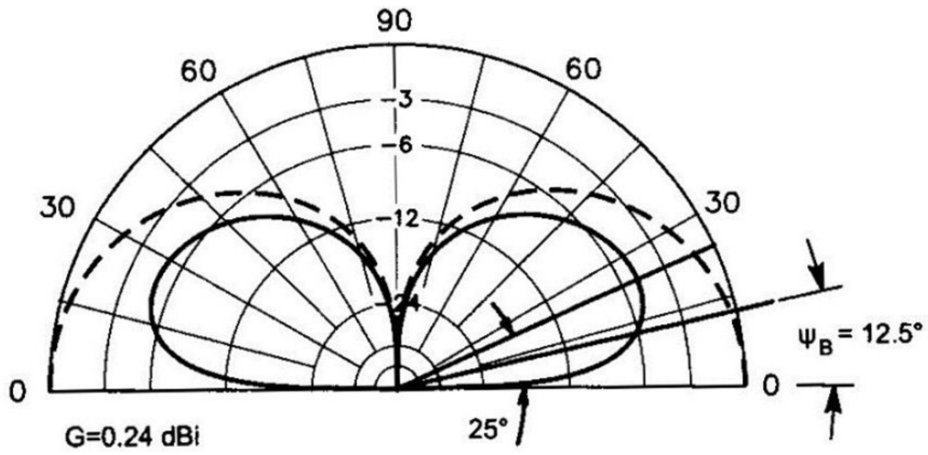
Vertical Antenna Ideal Radiation Pattern



Vertical antenna radiation pattern over perfect ground

- As the elevation angle increases from P_0 to some arbitrary point P, the time of travel to point P changes for both the direct and reflected waves, but not by the same amount
- Consequently, the signal strength (the sum of the direct and reflected waves) continually drops as the elevation angle increases, as shown in the figure
- Note that the signal strength at point P is 3db down from that a point P_0

Vertical Antenna Pattern Over Real Ground

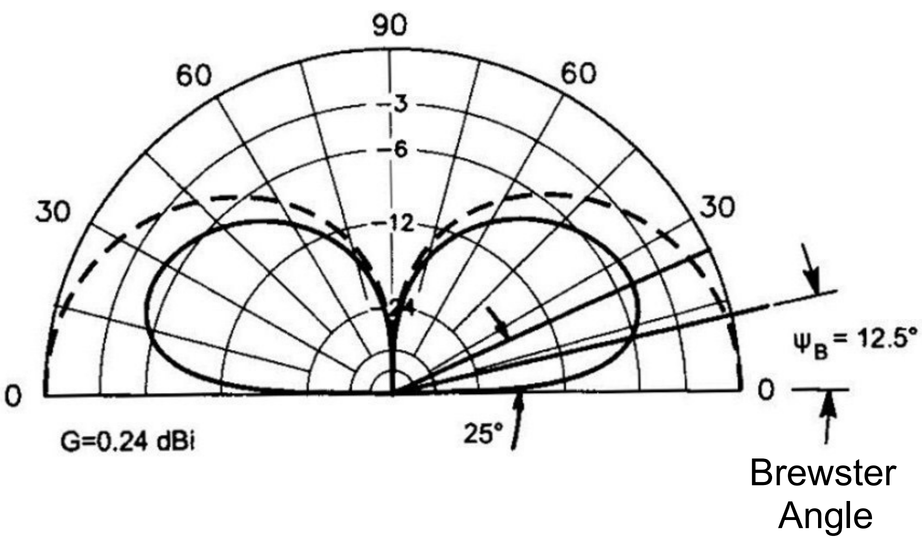


Dashed Line = Ideal vertical pattern

Solid Line = Pattern over real ground

- For real ground the reflection phase shift is -180 deg at an elevation angle of 0 deg
- Consequently the direct and reflected waves completely cancel forming a deep dull at a 0 deg elevation angle
- The reflection phase shift decreases as the elevation angle increases
- At some point the reflection phase shift drops to -90 deg

Pseudo Brewster Angle

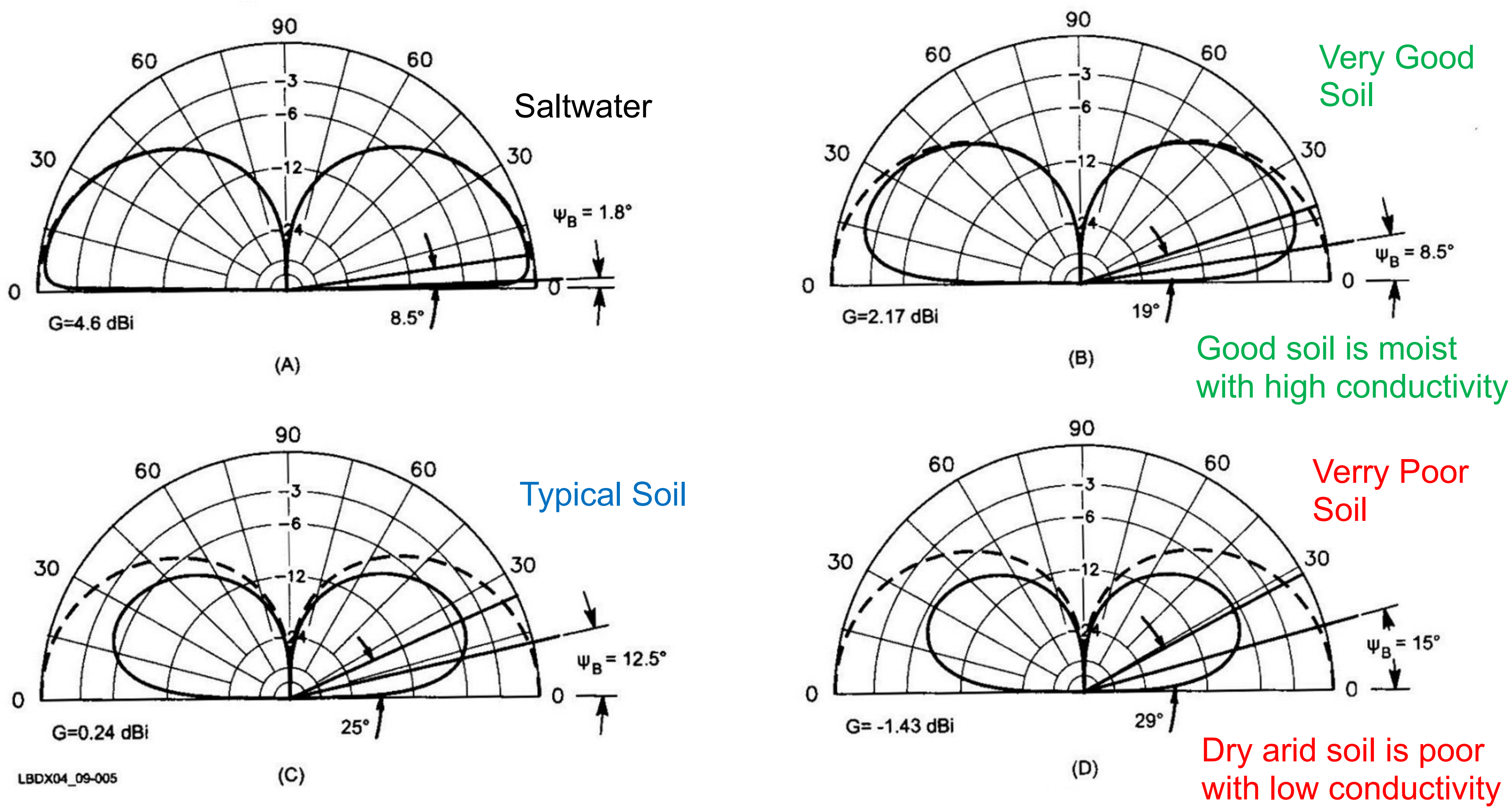


Dashed Line = Ideal vertical pattern

Solid Line = Pattern over real ground

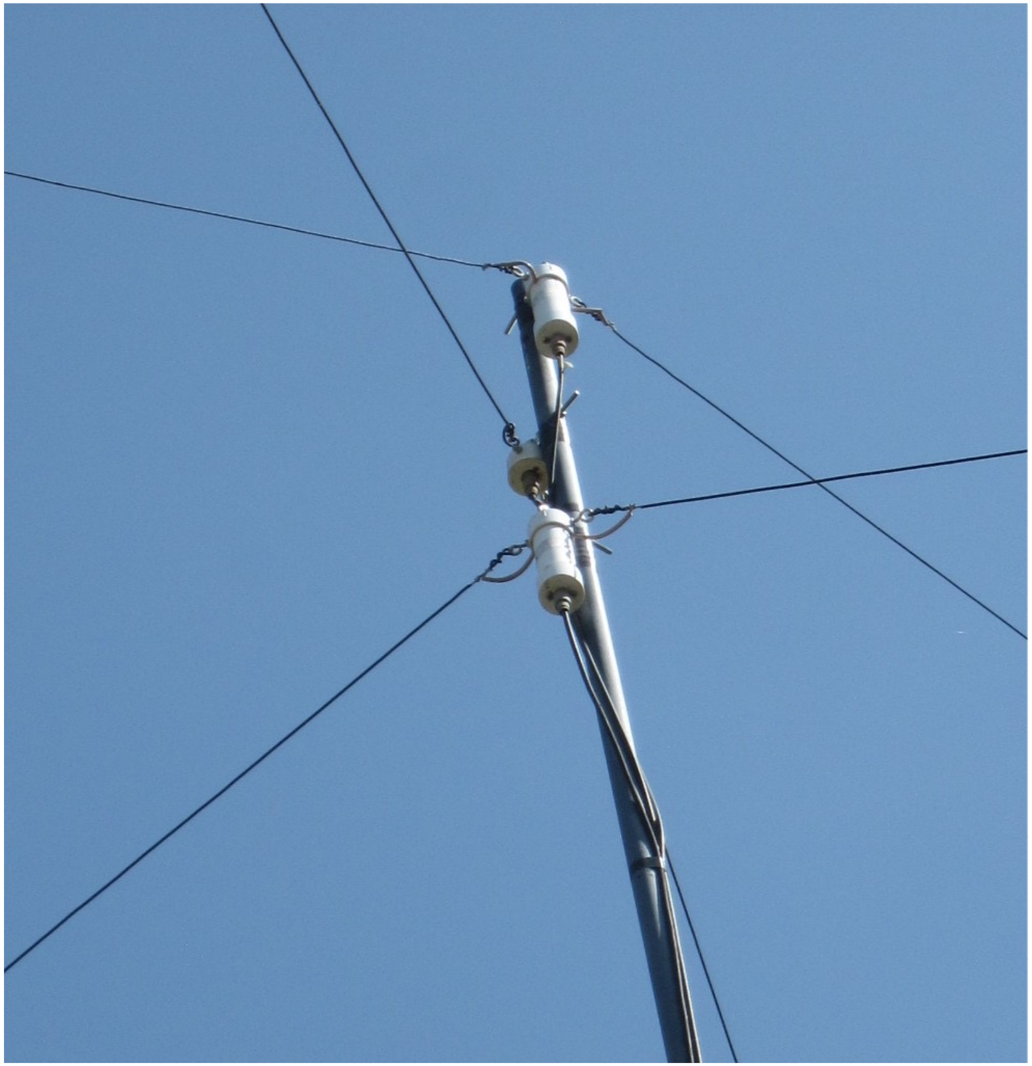
- The elevation angle at which the reflection phase shift drops to -90 deg is called the pseudo Brewster Angle
- Below the Brewster Angle the reflected wave subtracts from the direct wave
- Above the Brewster Angle the direct and reflected wave add

Soil Conditions Affect Pseudo Brewster Angle

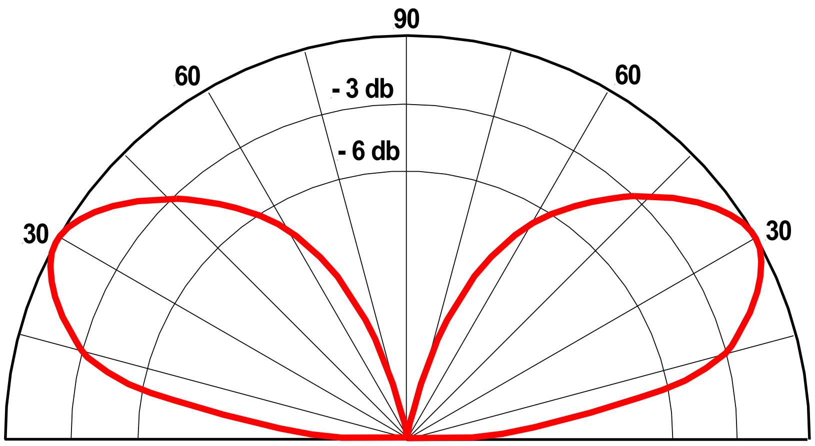


- Brewster Angle = 1.8^{o} over Saltwater, 8.5^{o} over Very Good Soil
- Brewster Angle = 12.5^{o} over Typical Soil, 15^{o} over Very Poor Soil

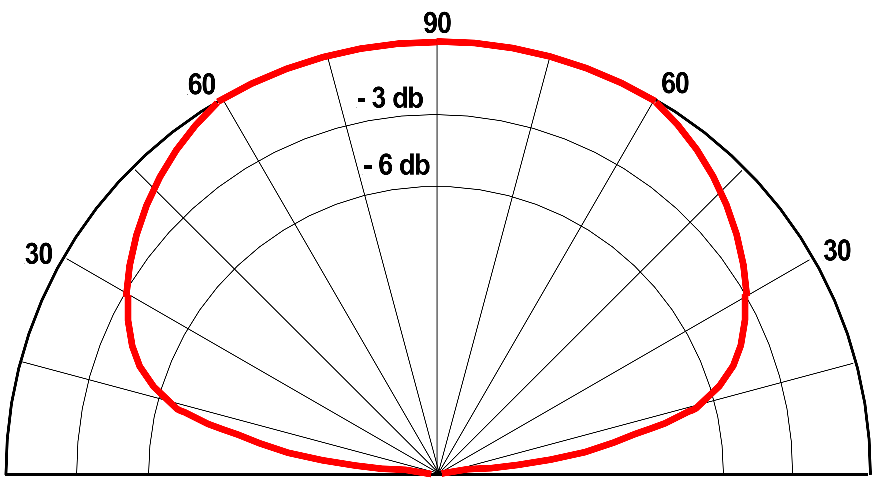
Radiation Patterns For Horizontal Antennas



Wide Antenna Radiation Patterns



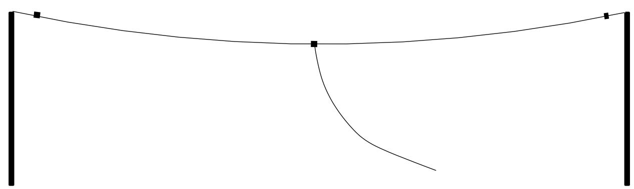
1/2 Wave Dipole Antenna At Optimum Height

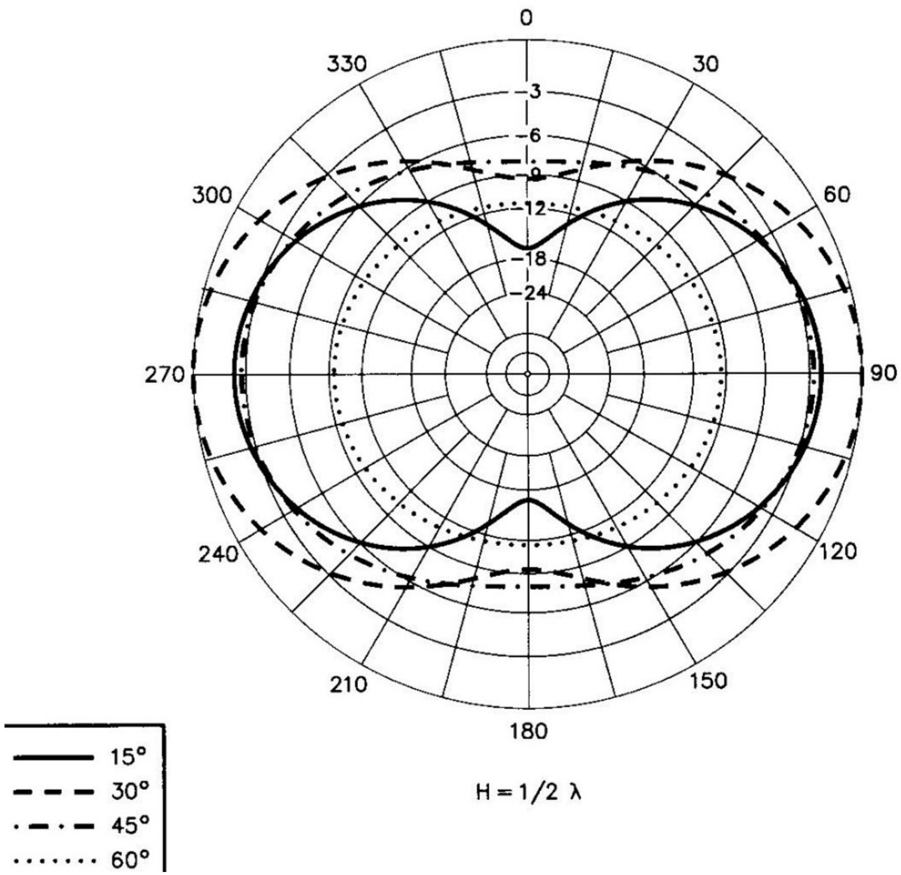


NVIS 1/2 Wave Dipole 1/4 Wavelenth Above Ground

- Like verticals
- **Horizontal dipole antennas are not lasers**
- In fact, a dipole antenna is also a relatively crude device illuminating large areas of the sky with its radiated energy

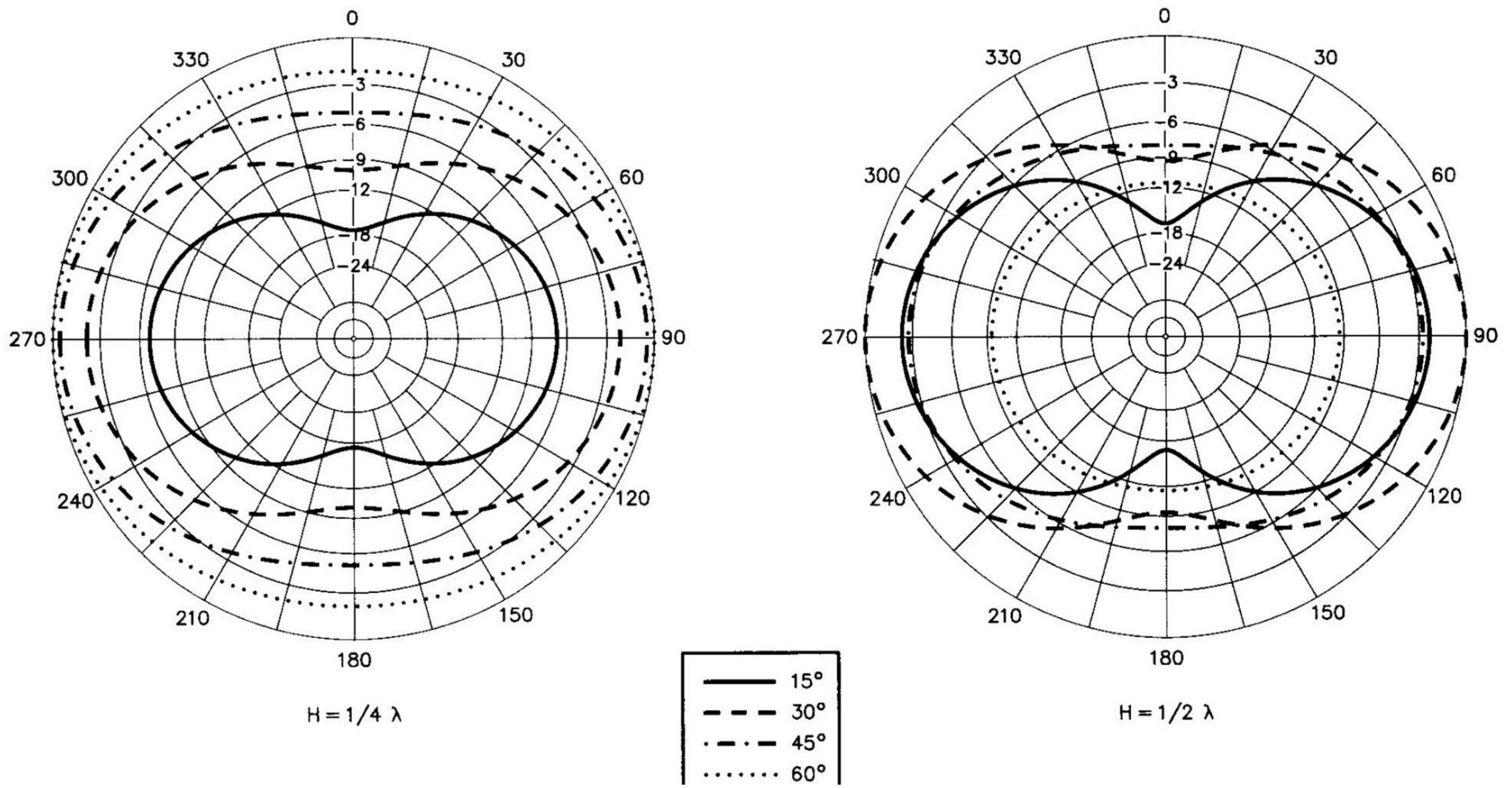
Dipole Radiation Pattern In Horizontal Plane





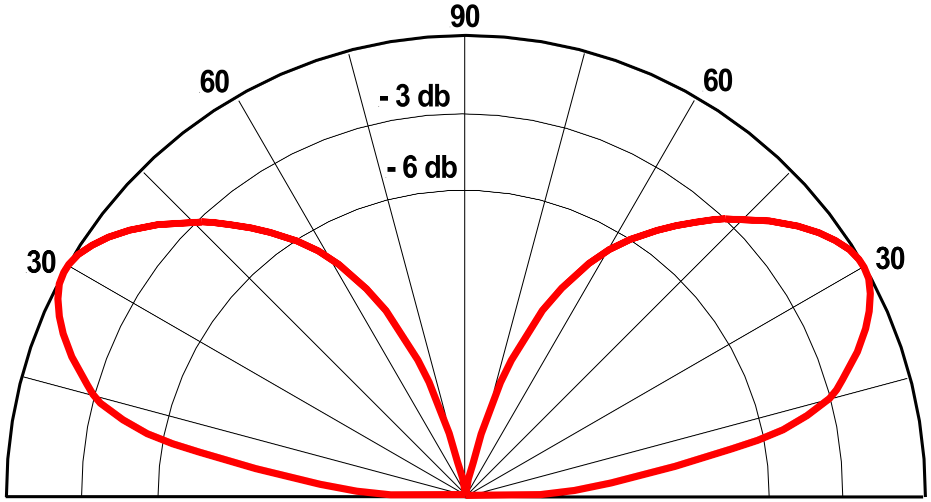
- Radiation pattern for a horizontal dipole 1/2 wavelength above ground measured at elevation angles of 15, 30, 45, and 60 deg
- In the figure the axis of the antenna is from 180 to 0 deg
- Most of the energy is radiated off the sides of the antenna (at 90° & 270°)
- Very little energy is radiated off the ends of the antenna (0° & 180°)
- A horizontal dipole 1/2 wavelength above ground is thus a directional antenna (to some extent)

Dipole Radiation Pattern In Horizontal Plane

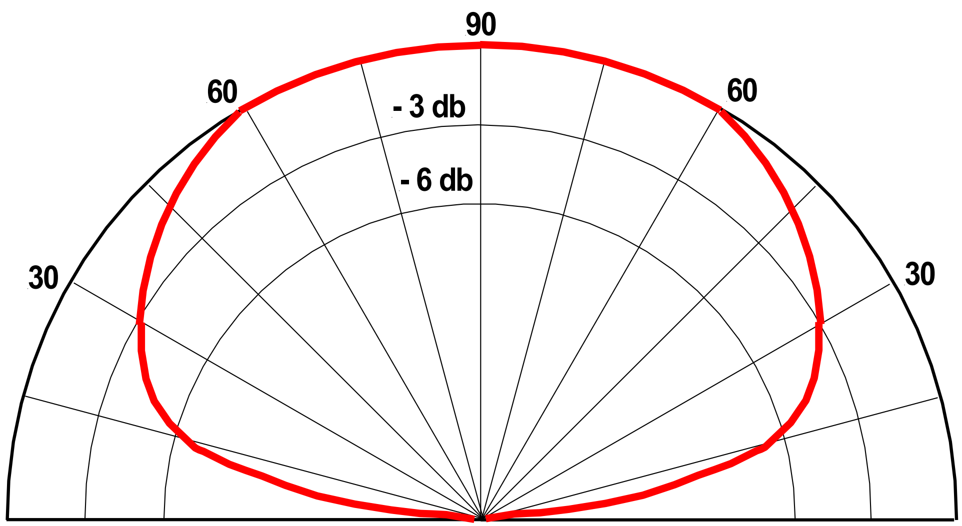


- Horizontal radiation pattern depends on the antenna’s distance above ground
- Horizontal radiation pattern becomes omni directional for an antenna less than 1/4 wavelength above ground (dotted circle in the above figures)

Dipole Vertical Radiation Patterns



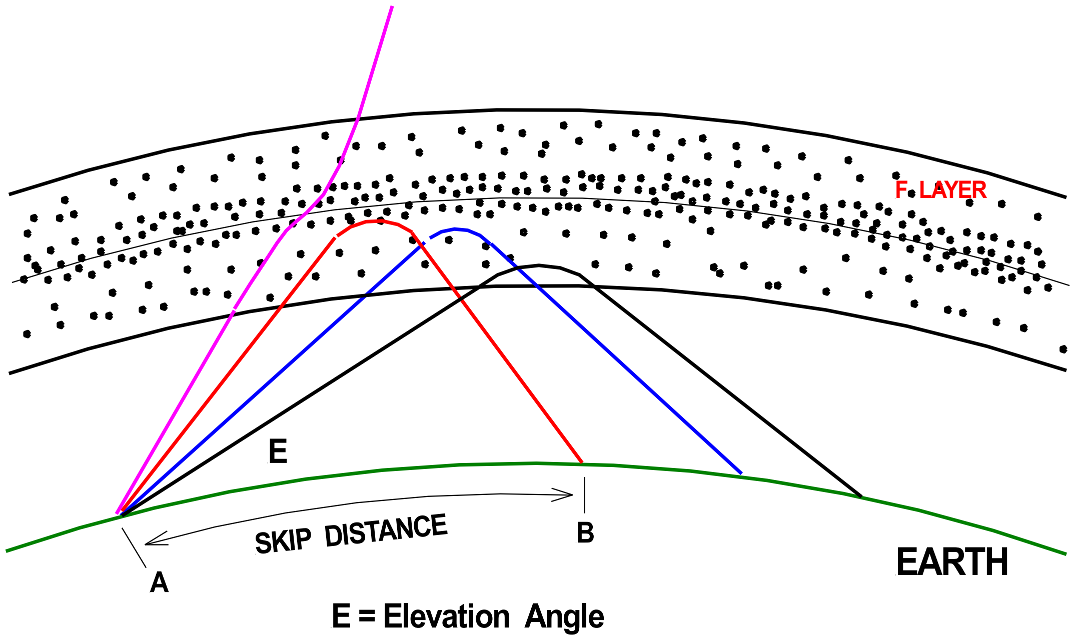
1/2 Wave Dipole Antenna At Optimum Height



NVIS 1/2 Wave Dipole 1/4 Wavelenth Above Ground

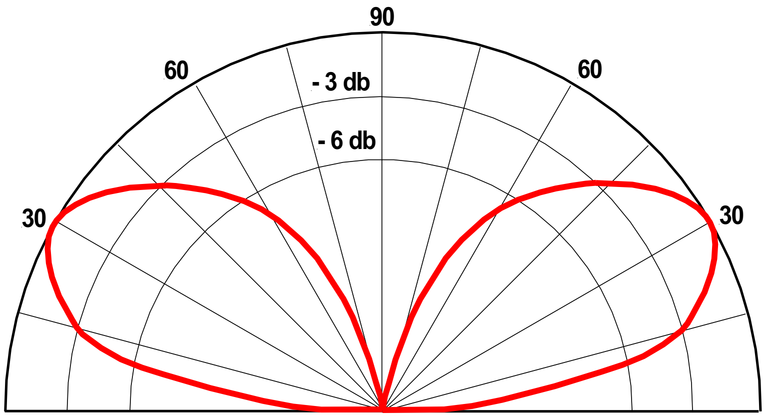
- Drawings show the radiation patterns of a horizontal dipole in the vertical plane
- The vertical pattern also depends on antenna's height above ground
- An antenna a half wave length above ground has a relatively low radiation pattern
- An antenna less than a quarter wavelength above ground has a high radiation pattern

Antenna Elevation Angle



- Again
- Signals radiated at low elevation angles propagate long distances (good DX)
- Signals travel shorter distances as the elevation angle E increases
- A signal will pass through the ionosphere and be lost to outer space if the elevation angle is too great
- For good DX we want antennas that radiate at low elevation angles

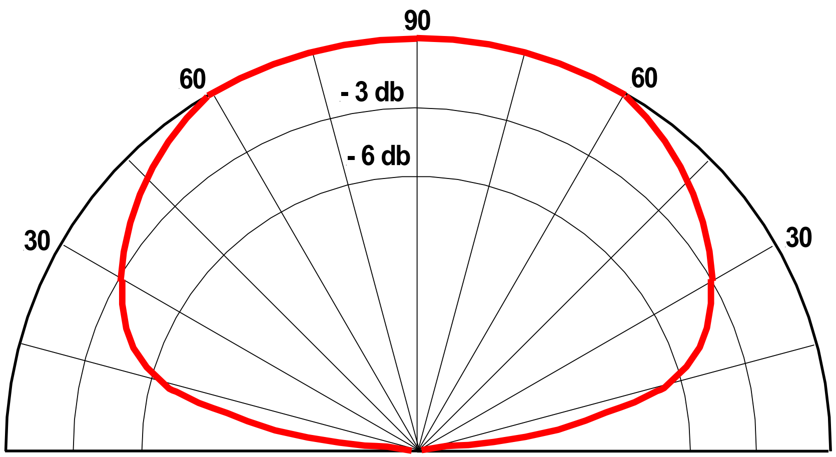
Horizontal Dipole a Good DX Antenna



1/2 Wave Dipole Antenna At Optimum Height

- Signal strength peaks at an elevation angle of 30º for a 1/2 wave dipole one half wavelength above ground (at its optimum height)
- This is a good elevation angle for long distance communication (DX)
- An elevation angle of 15º is even better
- Notice that for this antenna the radiated power at 15º is only 3 db below its 30º peak
- 3 db is only a half S-unit on the S meter of a receiver and barely detectable by the receiving operator
- Thus a 1/2 wavelength dipole one half wavelength above ground is an excellent DX antenna

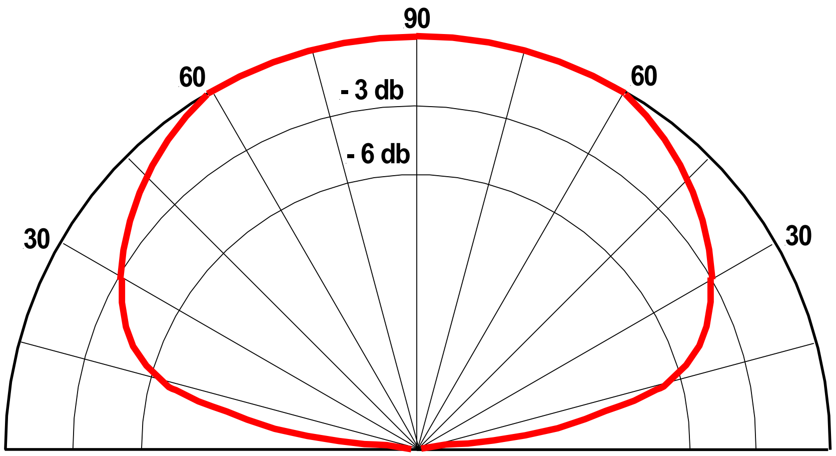
NVIS Antennas



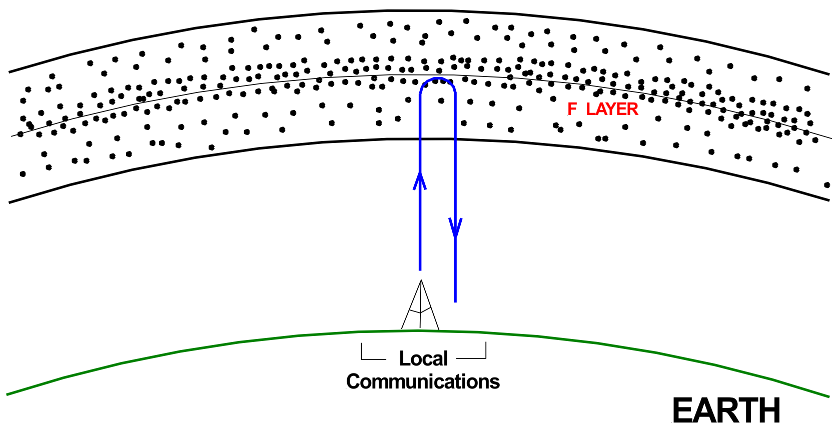
NVIS 1/2 Wave Dipole 1/4 Wavelenth Above Ground

- A 1/2 wave dipole less than one quarter wavelength above ground produces a high radiation angle
- This is a Near Vertical Incident Skywave (NVIS) antenna extremely important for short distance (close in) emergency communication work
- Note that the 3db point is at 30°
- An NVIS antenna is capable of transmitting a considerable distance

NVIS Antennas



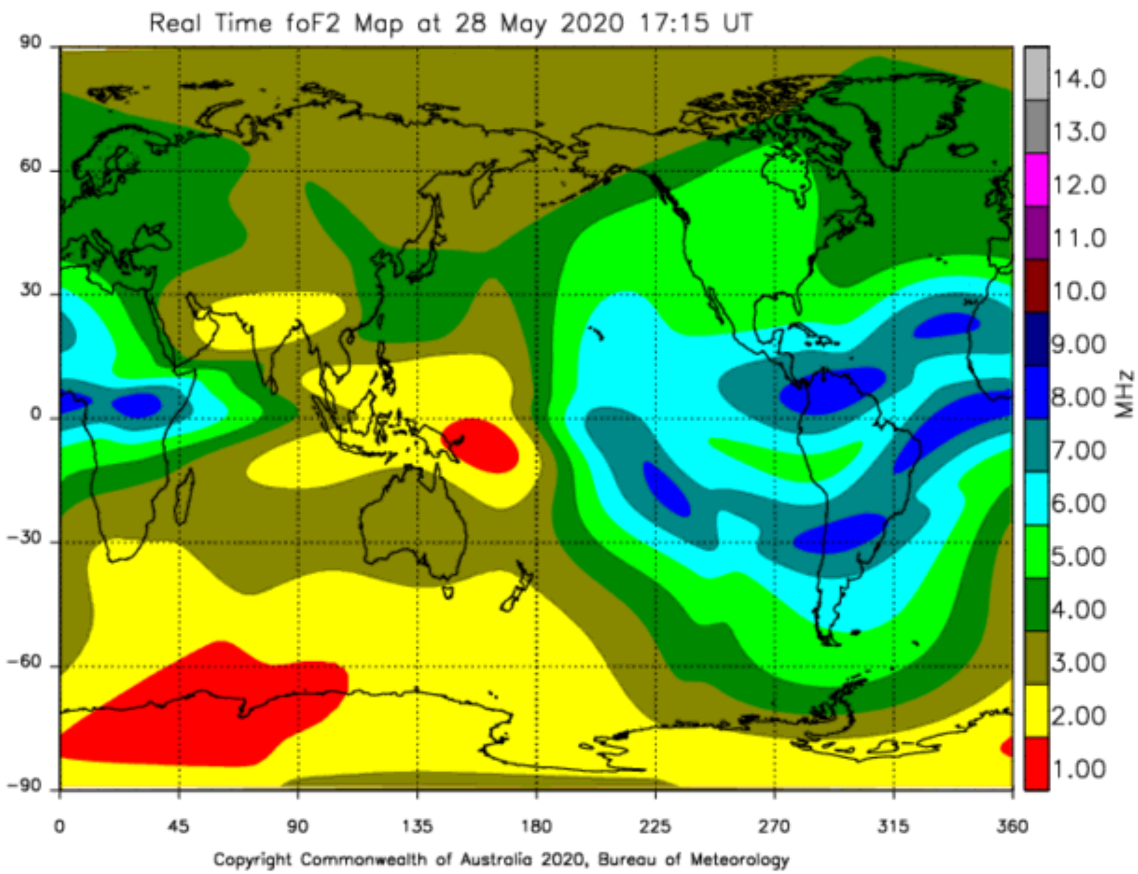
NVIS 1/2 Wave Dipole 1/4 Wavelenth Above Ground



Critical Frequency

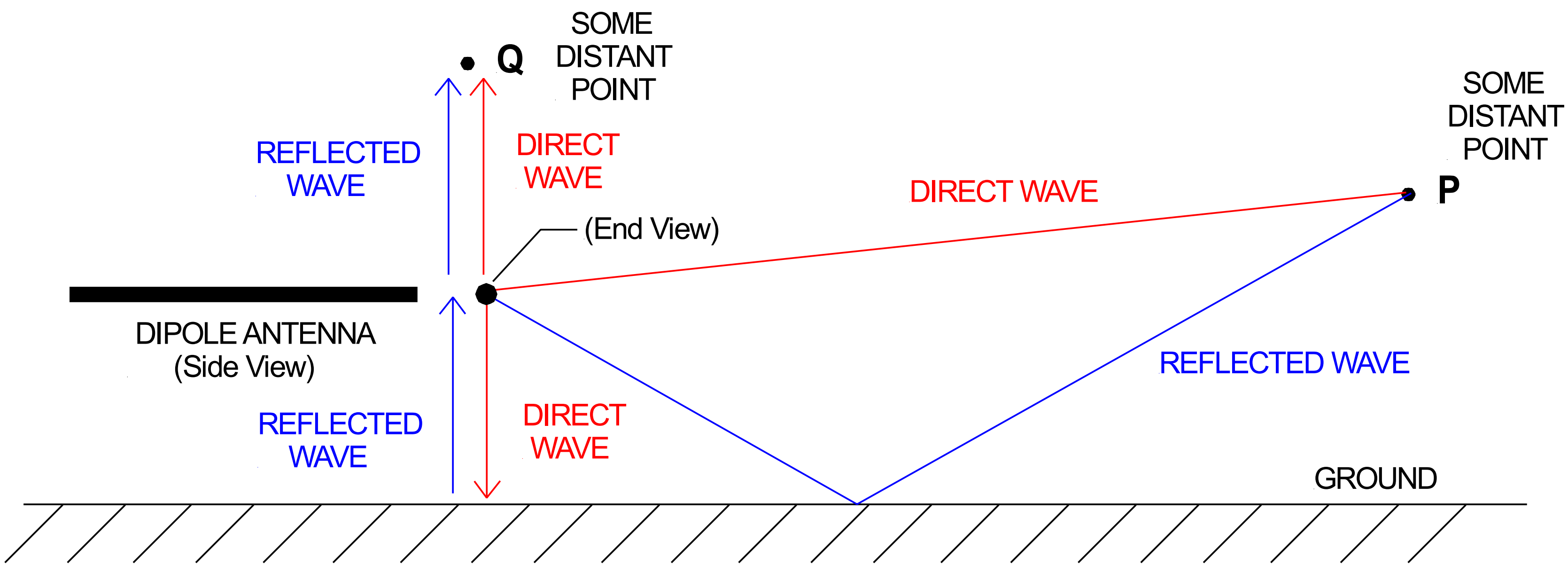
- Critical frequency is the highest frequency radio signal that can be transmitted straight up & reflected by back to Earth by the ionosphere
- An NVIS signal must be transmitted at or below the critical frequency
- 80, 60, and 40 meters are NVIS frequency bands
- 20 – 10 meters are not NVIS bands
- Most of the signal transmitted by a 20 meter dipole less than a quarter wavelength above ground will penetrate the ionosphere and be lost to outer space

Critical Frequency



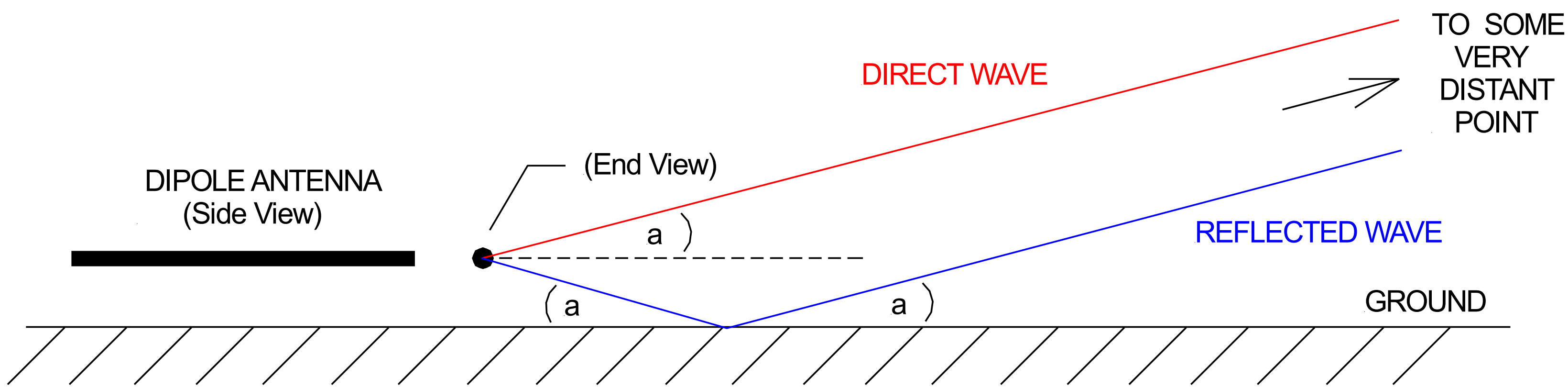
- Critical Frequency changes
  - Throughout the day
  - Seasonally
  - With the 11 year solar cycle
- The critical frequency over North America was 5 MHz when this map was made
- Too low for 40 meter NVIS operation
- 60 and 80 meters were the only usable NVIS bands at the time

Radiation From a Horizontal Dipole



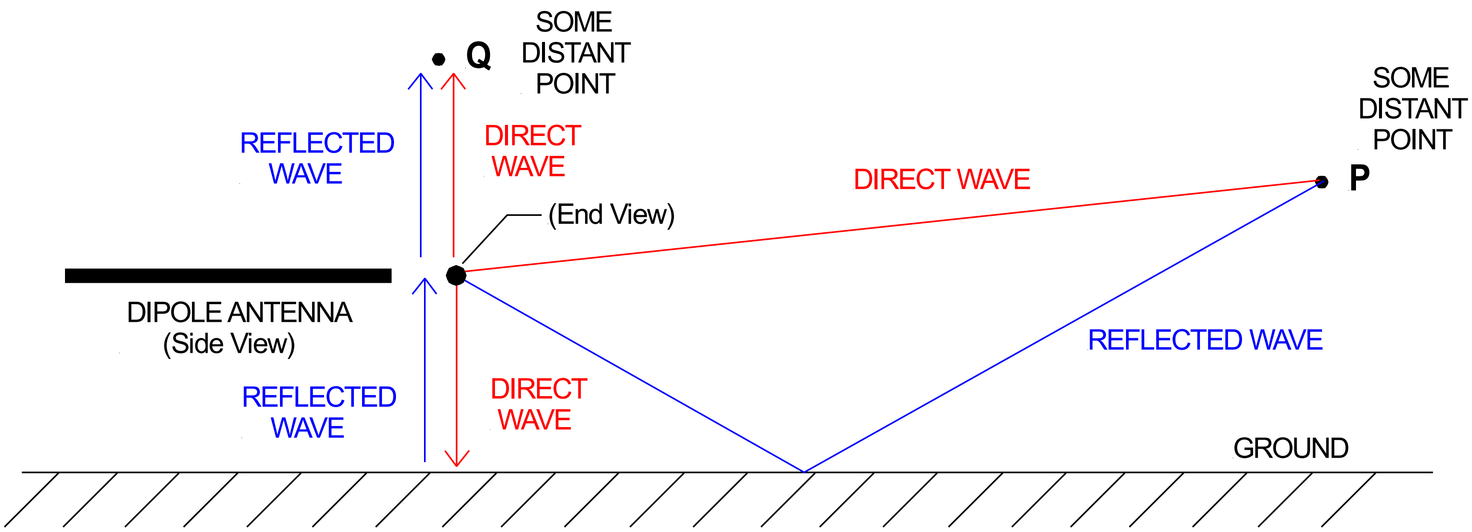
- Horizontal dipole antennas radiate
  - Upward,
  - Down, and
  - To both sides

Elevation Angle



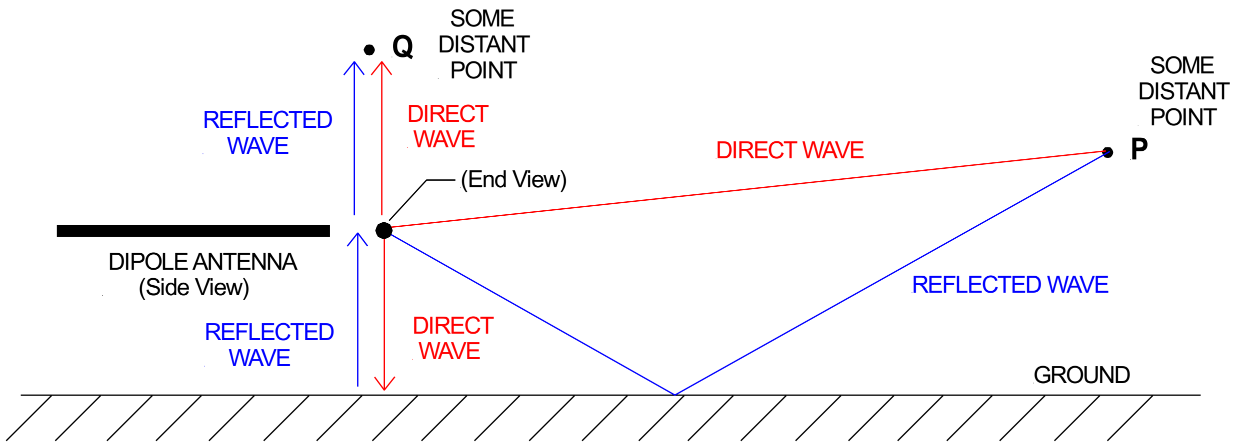
- Elevation angle is the angle “a” of the direct wave relative to a horizontal line
- The elevation angle for horizontal dipole antennas can range from -90 (straight down) to 0 (parallel to ground) to +90 deg (straight up).
- From geometry it turns out that the angle of incident of the reflected wave with the ground is the same as the elevation angle
- Also, from Snell’s Law, the angle of reflection equals the angle of incident

Direct and Reflected Wave Interaction



- An antenna's radiation pattern is determined by the interaction of the direct wave and the reflected wave at some distant point P
- This interaction is in turn affected by
  - The height of the antenna above ground, and
  - Soil conditions at the point of reflection

Radiated Signal Strength

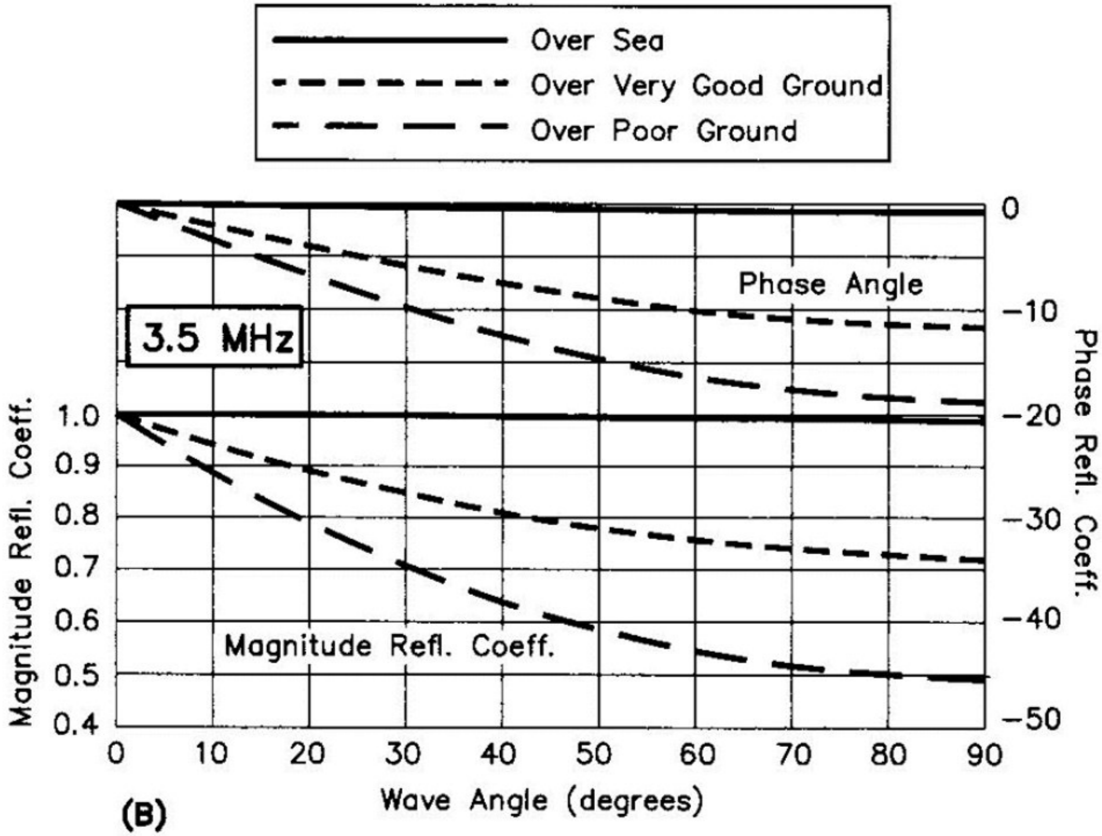


- The strength of the transmitted signal at a point P is the sum of the Direct Wave and the Reflected Wave
- The two waves add together if they are in phase, and subtract if they are out of phase
- The phase of the direct wave depends only on its travel time to Point P
- The phase of the reflected wave depends on both its travel time to Point P AND the phase shift incurred during reflection

Reflected Wave

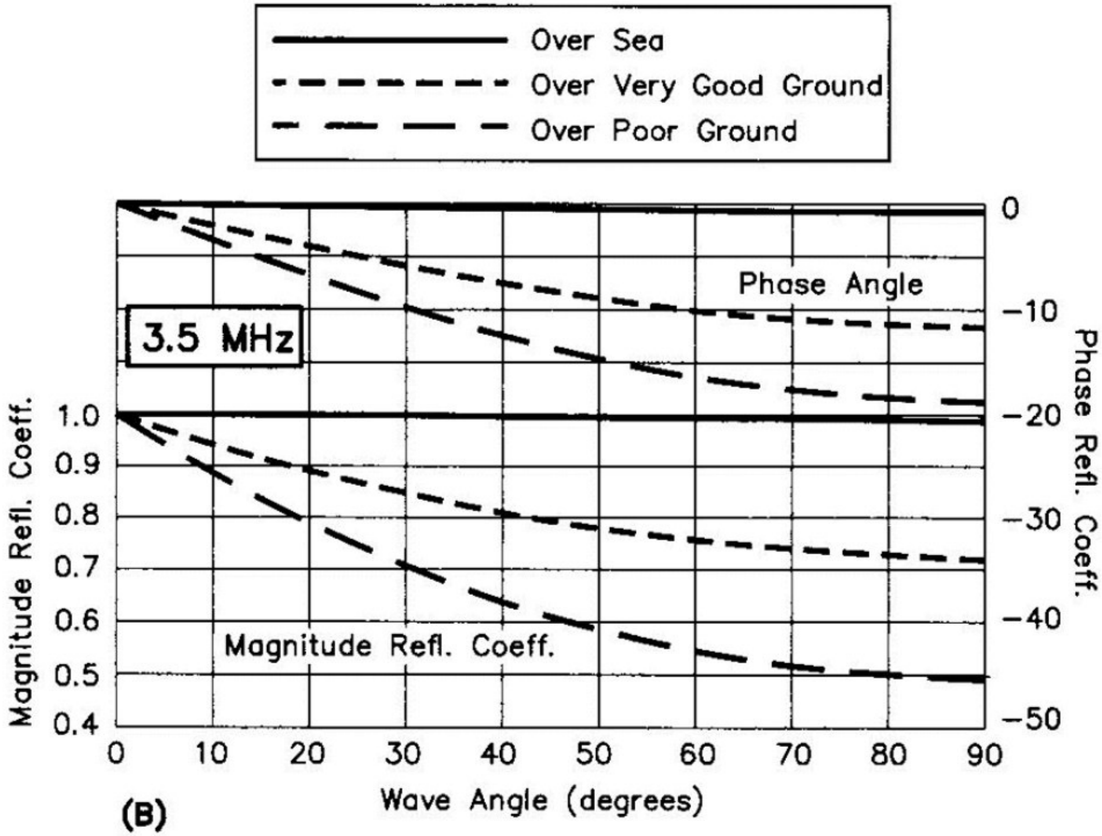
- The dielectric constant of air is approximately 1 while that of ground is much higher
- The higher dielectric constant causes the reflected wave to travel slower through ground at the reflection point resulting in a reflection phase shift
- A horizontally polarized wave reflecting from perfect ground (a mirror) encounters a 180 deg phase shift
- The phase shift of a horizontally polarized wave reflecting from poor ground deviates from 180 deg by generally no more than 25 deg
- The reflected wave is also attenuated as it passes through the ground at the reflection point
- Thus the reflected wave arrives at point P both attenuated and phase shifted

Typical Reflection Coefficients



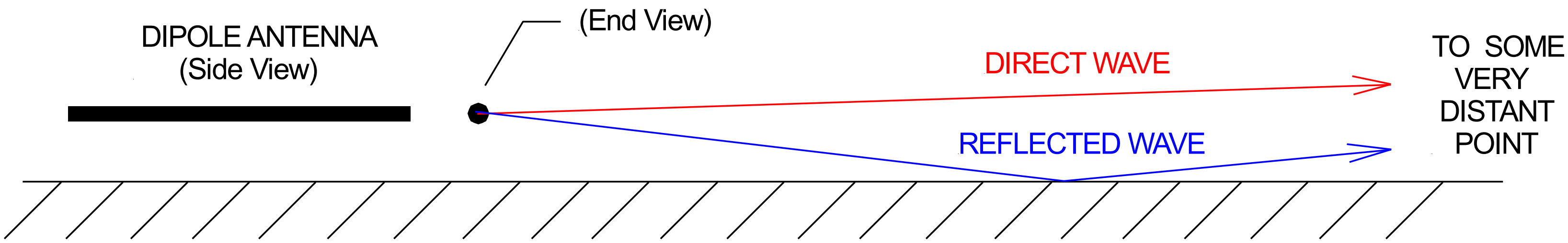
- Magnitude Coefficient and Phase Coefficient as a function of Wave Angle (Elevation Angle) for a 3.5 MHz horizontal dipole
- The magnitude of the reflected wave is attenuated by 50% at a wave angle of 90 deg over poor ground, much less at smaller wave angles

Typical Reflection Coefficients



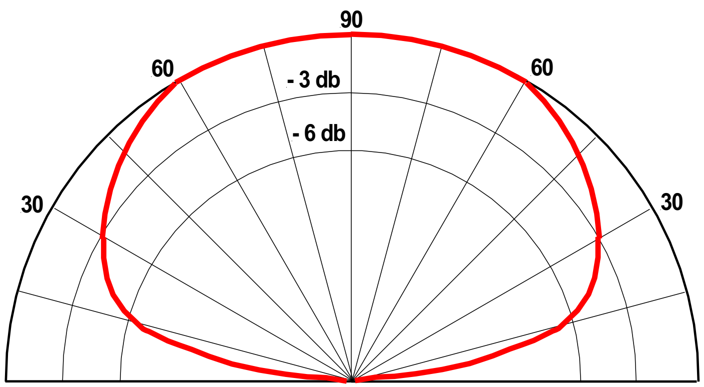
- Phase angle deviates from 180 deg by a max of -20 deg at a wave angle of 90 deg over poor ground, again much less at smaller wave angles
- A horizontally polarized antenna is not greatly affected by poor soil conditions

Signal Strength at Low Elevation Angle

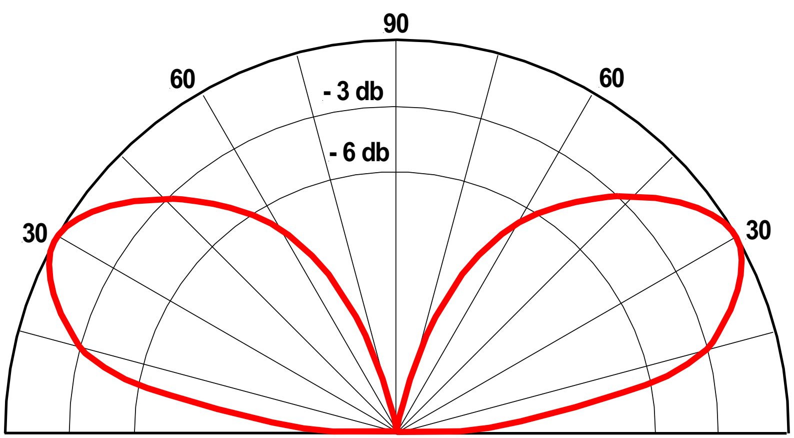


- For a very low (near 0 deg) elevation angle, the time of travel to some distant point is approximately the same for both the direct and the reflected waves
- Thus the phase shift as a result of travel time to the distant point is approximately the same for both the direct and reflected waves
- However, the reflected wave encounters an addition phase shift of 180 deg upon reflection
- Thus the two waves arrive at the distant point 180 deg out of phase, completely cancelling each other out

Signal Cancellation At Low Elevation Angle



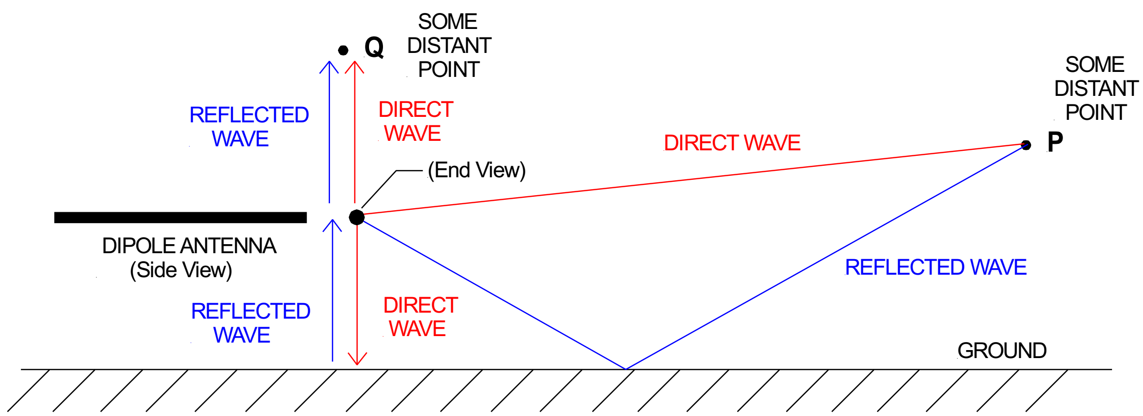
NVIS 1/2 Wave Dipole 1/4 Wavelenth Above Ground



1/2 Wave Dipole Antenna At Optimum Height

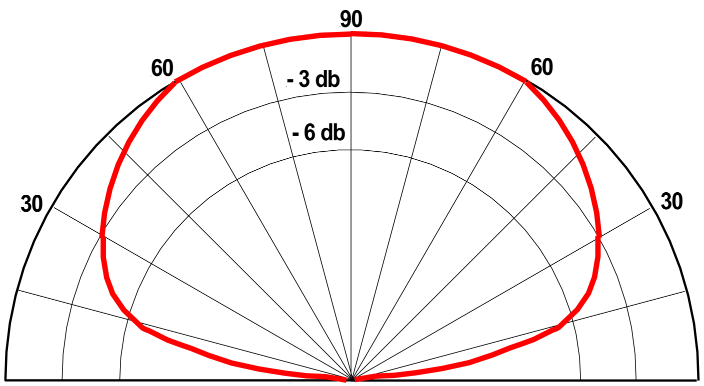
- The complete cancellation of a signal transmitted at a low elevation angle (0 to 10 deg) is evident in the radiation patterns for both the NVIS and the optimum DX antenna (an antenna at a height of 1/2 wavelength above ground)

High Angle Pattern – Antenna Up 1/4 Wavelength



- A direct wave shifts 90 deg traveling vertically down from the antenna to the ground
- 180 deg phase shift occurs upon reflecting from the ground
- The reflected wave shifts 90 deg more traveling back to the antenna
- Total round trip phase shift from the antenna to the ground and back to the antenna is thus 360 deg
- Reflected wave arrives back at the antenna in phase with the direct wave being radiated upward
- Two waves add creating maximum signal strength at Point Q

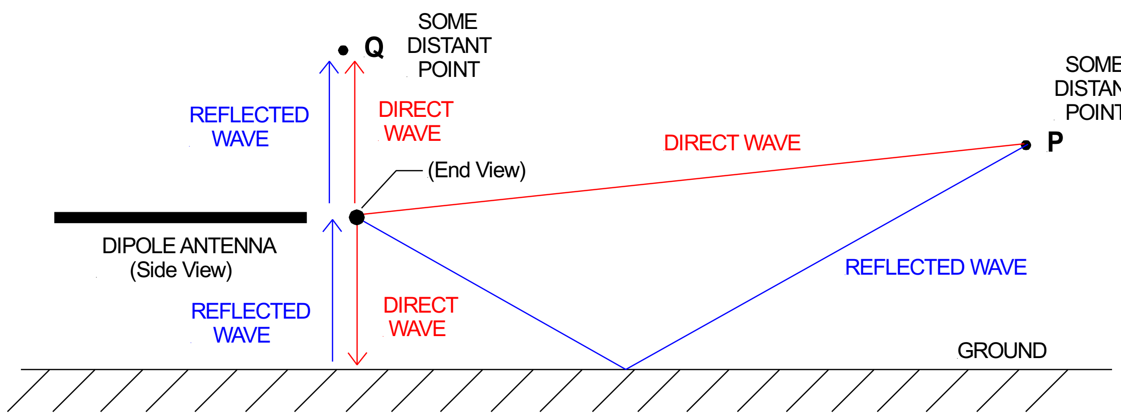
Dipole 1/4 Wavelength Above Ground



NVIS 1/2 Wave Dipole 1/4 Wavelenth Above Ground

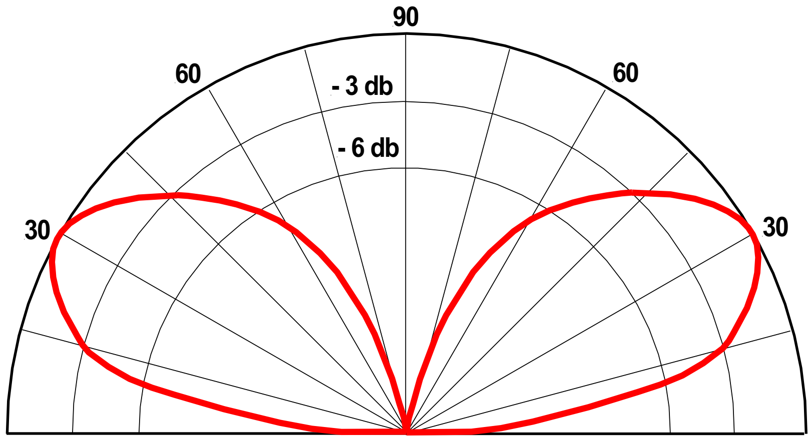
- The reflected wave and the upward direct wave add together for a dipole 1/4 wavelength above ground
- For this configuration the antenna's maximum signal strength occurs at an elevation angle of 90 deg

High Angle Pattern – Antenna Up 1/2 Wavelength



- A direct wave shifts 180 deg traveling to the ground
- 180 deg phase shift occurs upon reflecting from the ground
- Reflected wave shifts 180 deg more traveling back to the antenna
- Total round trip phase shift from the antenna to the ground and back to the antenna is thus 540 deg
- Reflected wave arrives back at the antenna 180 deg out of phase with the direct wave being radiated upward
- Two waves cancel resulting in no signal at Point Q

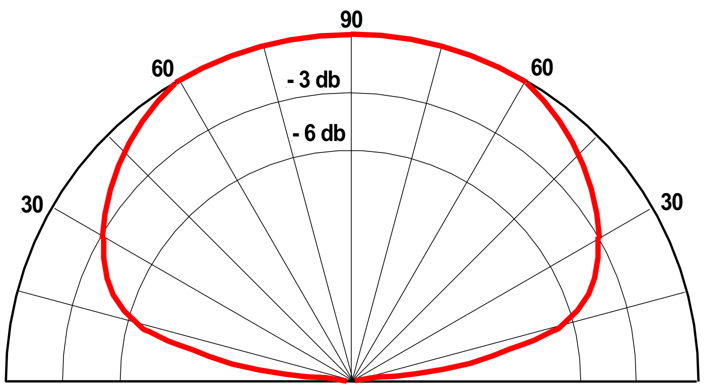
Dipole 1/2 Wavelength Above Ground



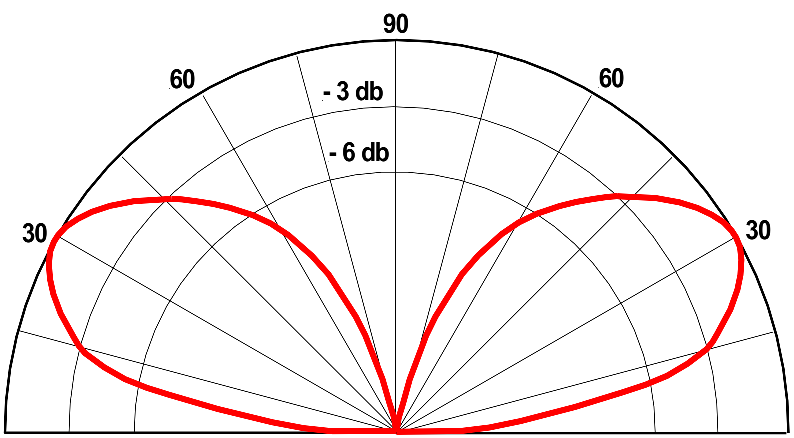
1/2 Wave Dipole Antenna At Optimum Height

- The reflected wave and the upward direct wave cancel for a dipole 1/2 wavelength above ground
- For this configuration a deep null (no signal) occurs at an elevation angle of 90 deg

Horizontal Dipole Radiation Pattern



NVIS 1/2 Wave Dipole 1/4 Wavelenth Above Ground

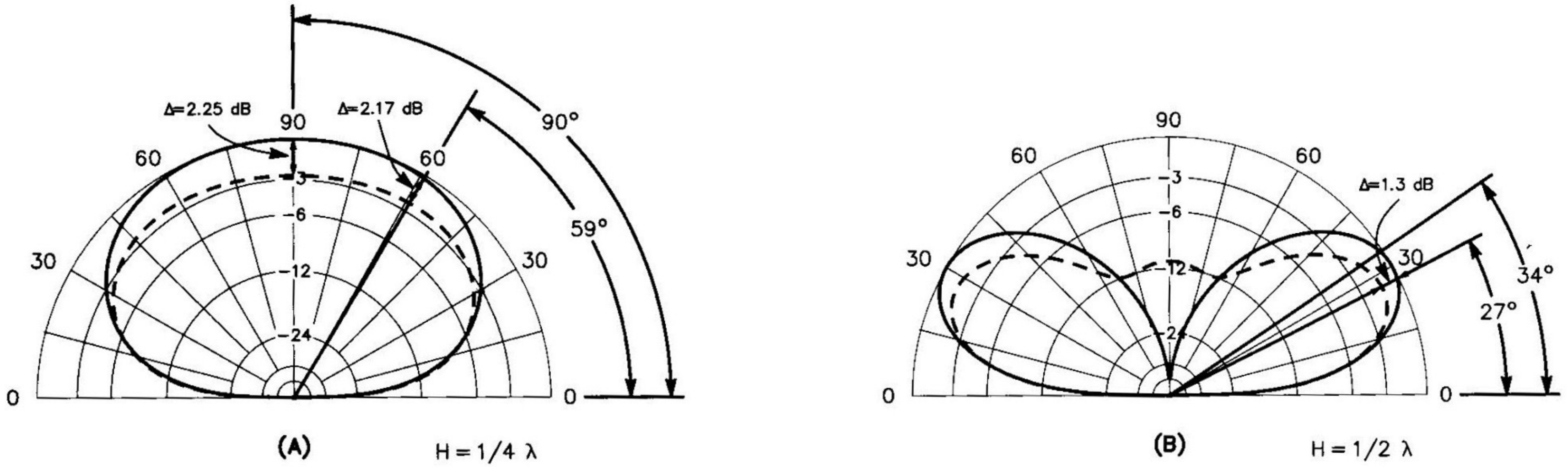


1/2 Wave Dipole Antenna At Optimum Height

- The radiation pattern of a horizontal dipole, in the vertical plane, at all elevation angles from 0 to 90 deg is a combination of the high angle and low angle direct wave and reflected wave interactions

- The interaction between the high angle direct wave and the high angle reflected wave depends on the height of the antenna above ground

Radiation Pattern Depends on Ground Quality

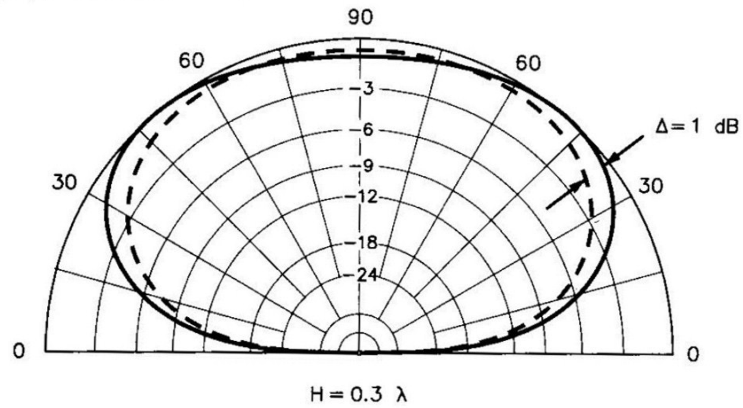


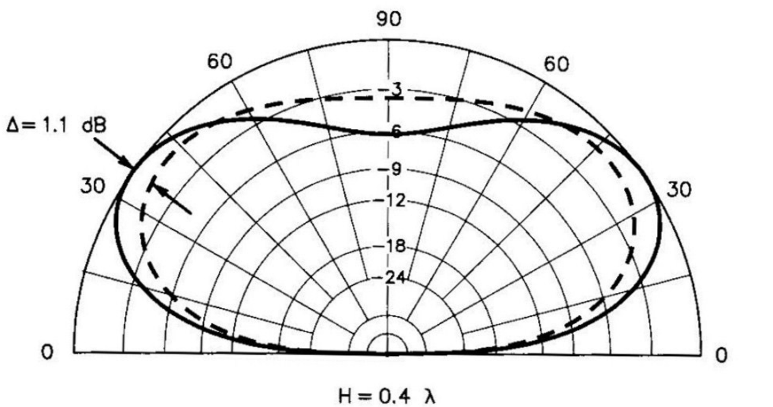
——————— Radiation pattern over perfect ground

- - - - - Radiation pattern over poor ground

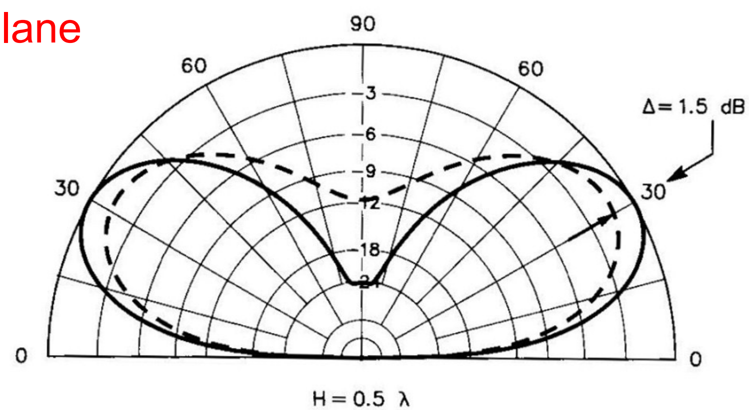
- Radiation patterns for 2 horizontal dipoles, one at 1/4 the other at 1/2 wavelength above perfect and poor ground
- Ground quality has only a small affect on horizontal antennas
- Ground quality severely affects vertical antennas

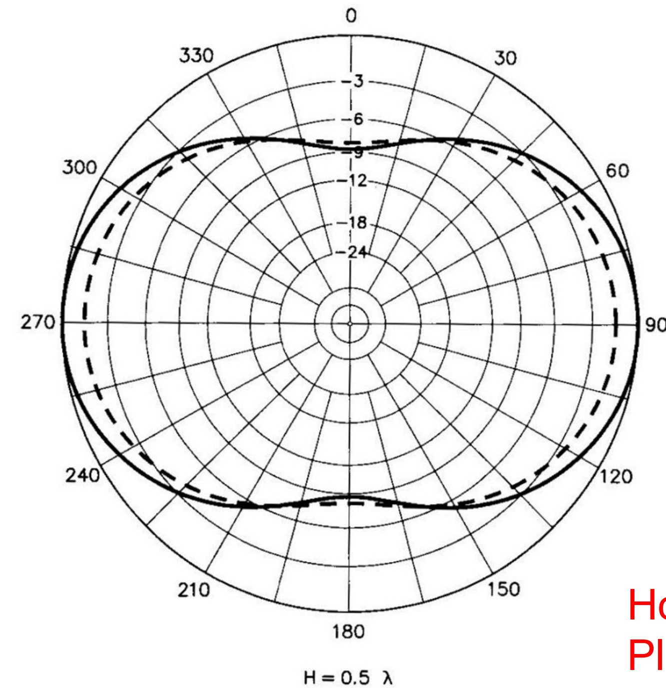
Inverted-V Antenna Radiation Patterns





Vertical Plane



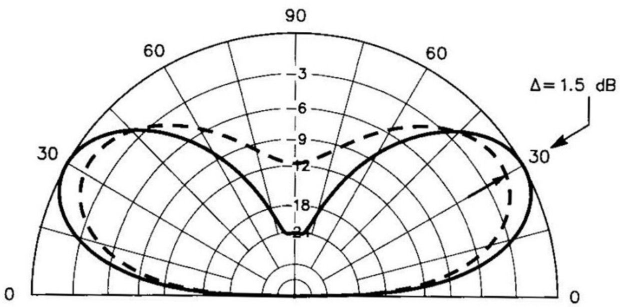


Horizontal Plane

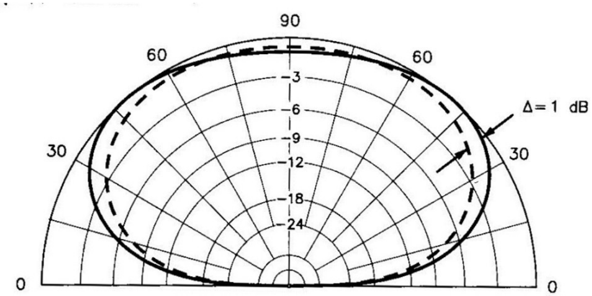
Horizontal Dipole — — — Inverted-V

Inverted V antenna patterns are nearly the same as a horizontal dipole

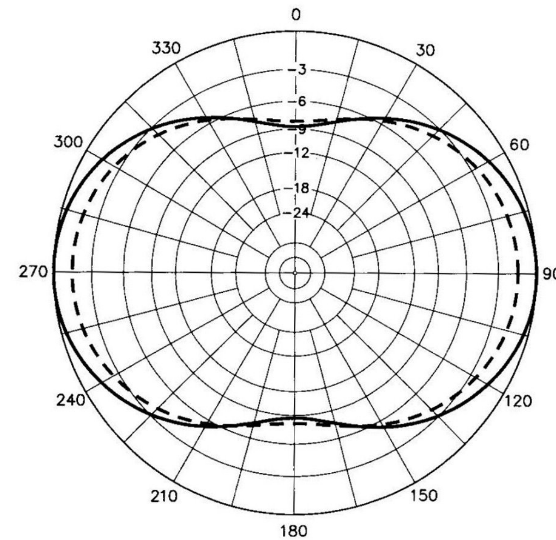
End Fed Half Wave Antenna Performance



H = 0.5 λ



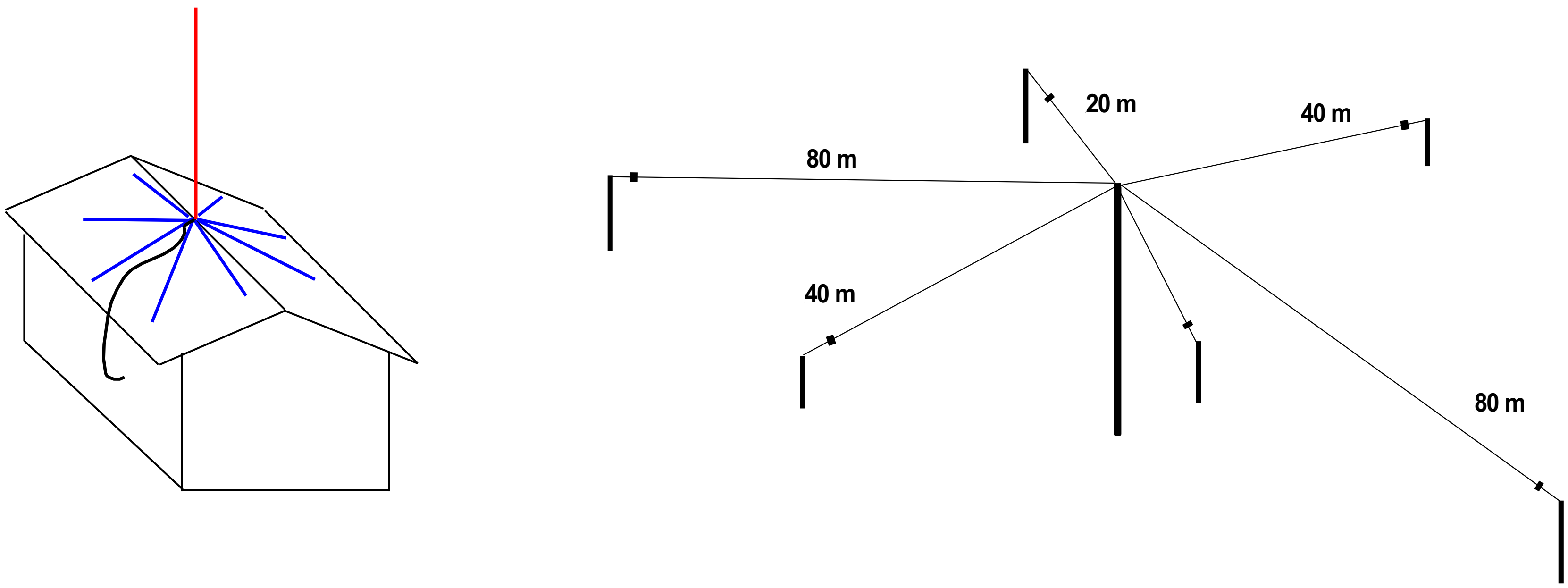
H = 0.3 λ



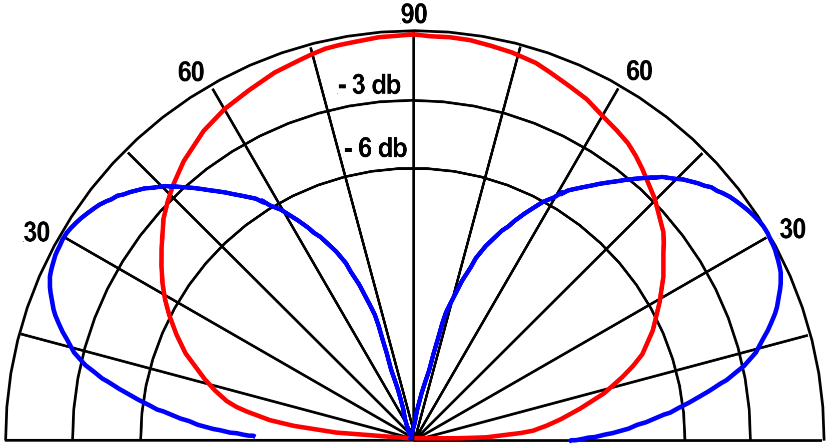
H = 0.5 λ

- The performance of an EFHW antenna is the same as its horizontal dipole or Inverted V counterpart
- In addition, an EFHW is inherently multi-band
- An EFHW cut for 7.0 MHz will also work on 20, 15, and 10 meters in addition to 40 meters

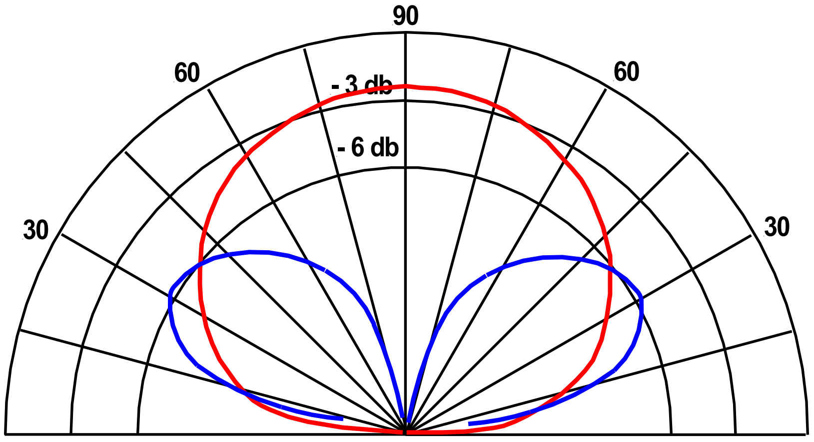
Comparison of Antennas



Comparison of 80m Elevation Patterns



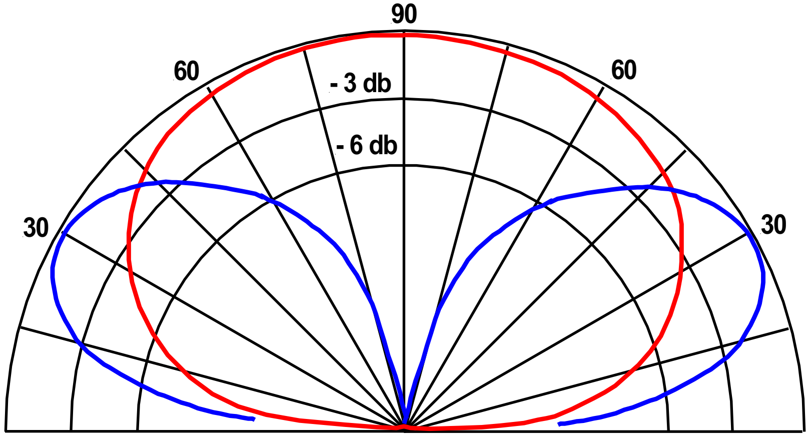
Good Soil



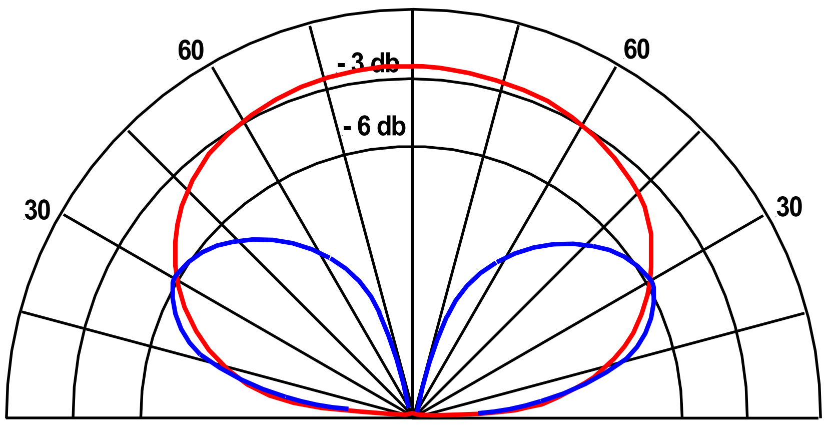
Poor Soil

- Blue = Vertical antenna, Red = Dipole 1/8 wavelength above ground (@ 32 feet)
- An 80 meter vertical antenna out performs an 80 meter horizontal NVIS antenna for DX work
- For close in high elevation work, NVIS antenna works better

Comparison of 40m Elevation Patterns



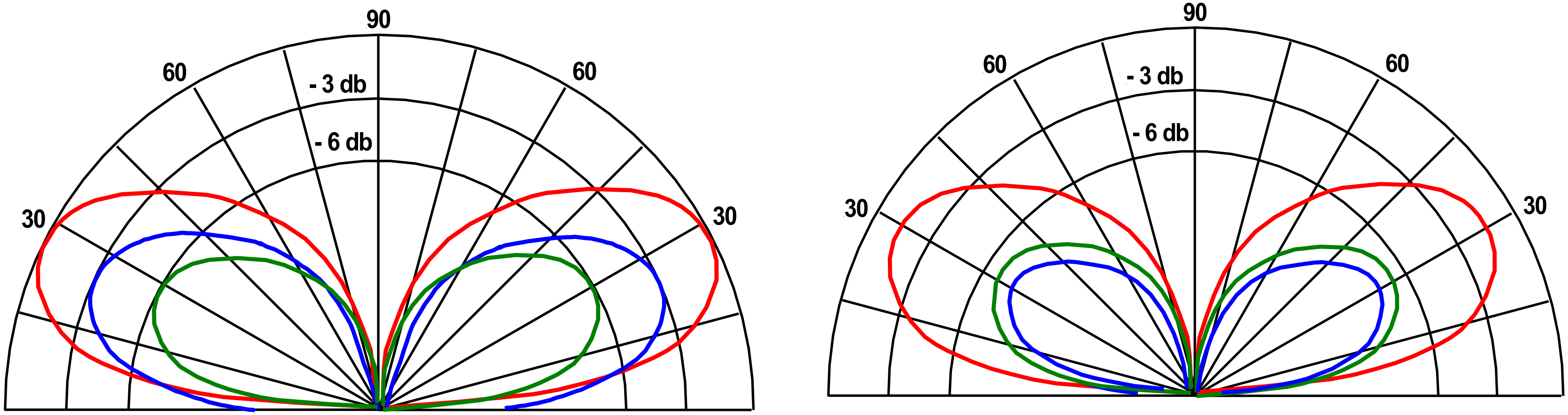
Good Soil



Poor Soil

- Blue = Vertical antenna, Red = Dipole 1/4 wavelength above ground (@ 32 feet)
- Over good soil a 40 meter vertical antenna out performs a 40 meter NVIS antenna for DX work
- Over poor soil a 40 meter vertical antenna and a 40 meter horizontal NVIS antenna perform the same for DX work (you can not tell them apart)
- For close in high elevation work, NVIS antenna works better

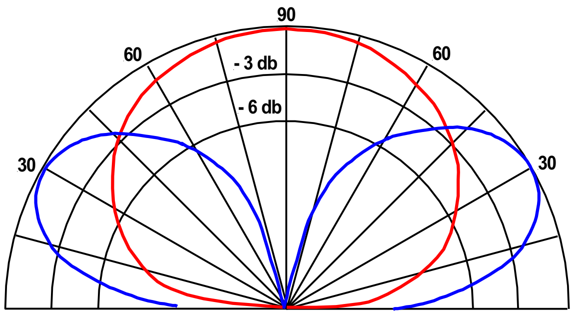
Comparison of 20m Elevation Patterns

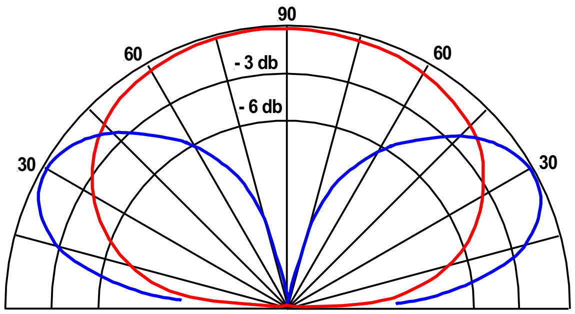


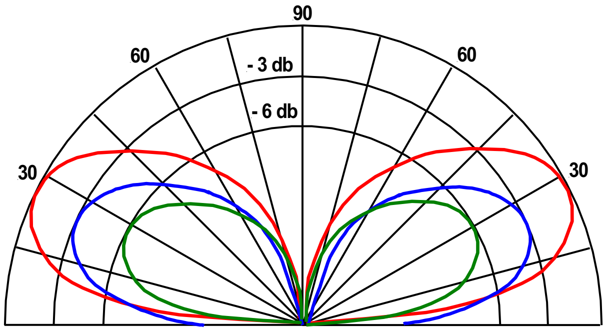
Good Soil Poor Soil

- Blue = Vertical,
- Red = Dipole (broadside) at 1/2 wavelength above ground (@ 32 feet)
- Green = Dipole (end pattern) at 1/2 wavelength above ground
- At 20 meters and above, horizontal antennas out perform vertical antennas

Over Good Soil – Vertical vs Dipole







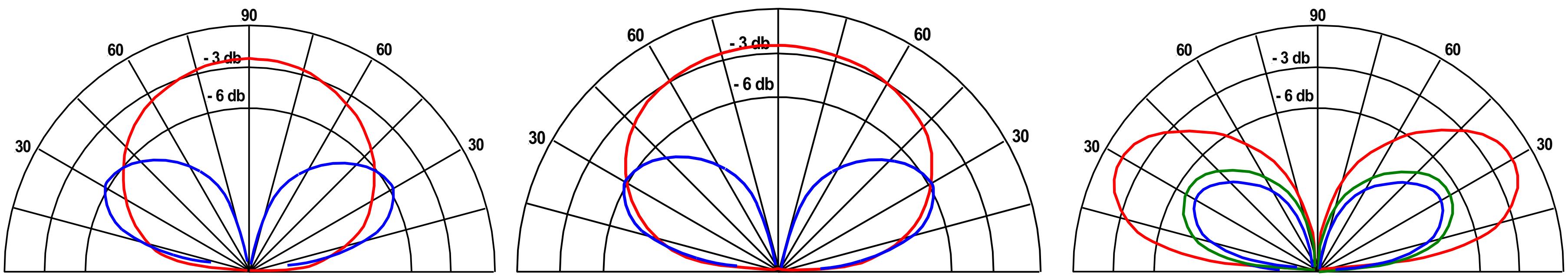
Dipole @ 1/8 wavelength above ground

Dipole @ 1/4 wavelength above ground

Dipole @ 1/2 wavelength above ground

- Blue = Vertical antenna,
- Red = Dipole antenna
- These charts shown the elevation patterns for a vertical antenna over good soil vs that of a horizontal dipole at various heights above ground on any given frequency band – dipole DX performance improves with height above ground
- At a height = 1/2 wavelength dipole outperforms a vertical over good ground

Over Poor Soil – Vertical vs Dipole



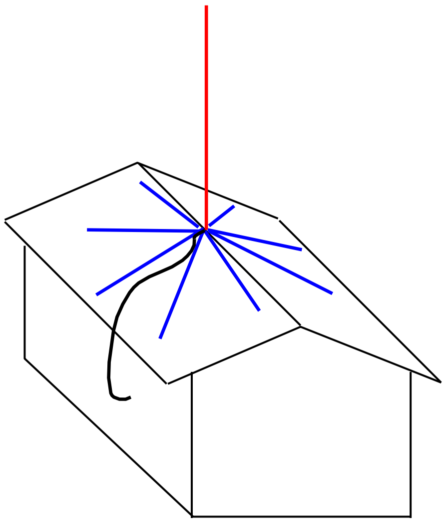
Dipole @ 1/8 wavelength above ground

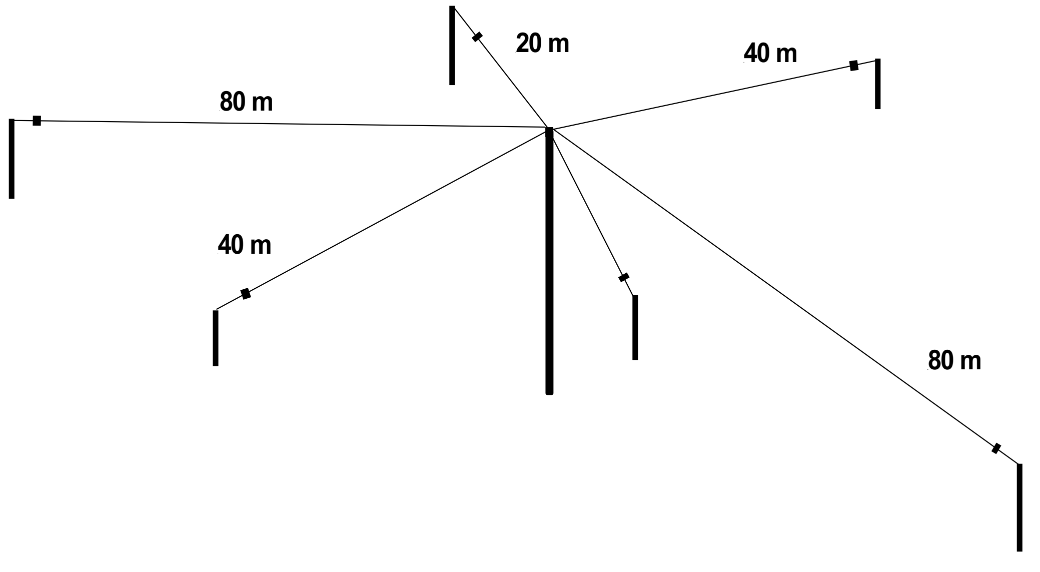
Dipole @ 1/4 wavelength above ground

Dipole @ 1/2 wavelength above ground

- Blue = Vertical antenna,
- Red = Dipole antenna
- These charts shown the elevation patterns for a vertical antenna over poor soil vs that of a horizontal dipole at various heights above ground on any given frequency band - dipole DX performance improves with height above ground
- At a height > 1/4 wavelength dipole outperforms a vertical over poor ground

Conclusion



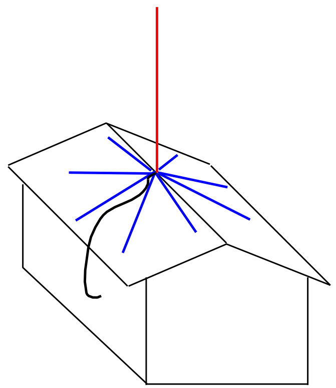


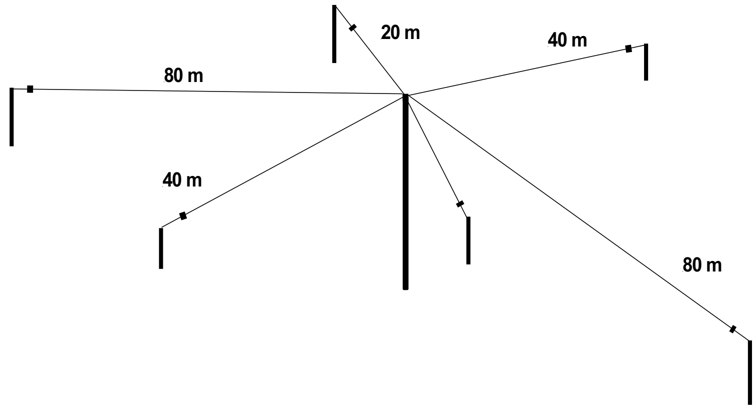
RULE #1

- **Put up the best antenna system you can given your:**
  - Cost constraints,
  - Available space,
  - CC&R restrictions, and
  - other constraints

- **Be happy with your results because:**
  - You did your homework and
  - Installed the best antenna possible for your situation
  - Your results will probably be better than expected and very gratifying

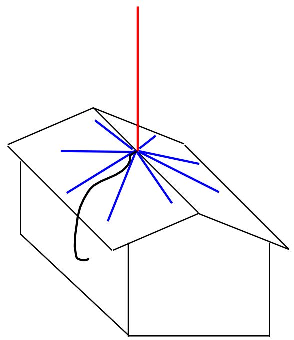
Vertical vs Horizontal Conclusions

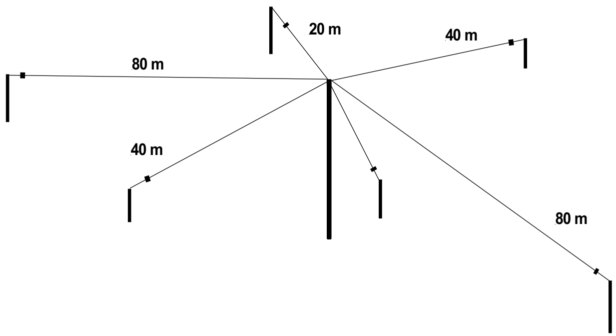




- In semi-arid Southwestern United States horizontal antennas are generally better DX antennas than verticals with the exception of 80 meter verticals
- The situation is different in other parts of the country where vertical antennas can be excellent DX performers on 80 and 40 meters
- The DX performance of vertical antennas improves with soil conditions
- DX performance of horizontal antennas improves with height above ground
- Horizontal antennas generally outperform verticals on 20 thru 10 meters, which is one reason why Yagis are horizontal antennas

More Conclusions





- For NVIS (close in) emergency communications work, horizontal antennas far out perform verticals
- In general horizontal dipole antennas are easier to install than verticals
- Installing radials for a 1/4 wavelength vertical is a time consuming project, assuming that you have space to install a radial system
- The available 1/2 wavelength no radial vertical antennas are relatively complex heavy antennas which are fairly difficult to install
- However, 1/2 wavelength no radial vertical antennas consume far less space than other antenna alternatives