Technical Report 2027
September 2013

# Directional Array for Near Vertical Incident Skywave (NVIS)

## A NISE funded
## Basic Research Project

Thomas O. Jones III

SSC Pacific
San Diego, CA 92152-5001

Technical Report 2027
September 2013

# Directional Array for Near Vertical Incident Skywave (NVIS)

## A NISE funded Basic Research Project

Thomas O. Jones III

SSC Pacific
San Diego, CA 92152-5001

**SSC Pacific**
**San Diego, California 92152-5001**

**J. J. Beel, CAPT, USN**
**Commanding Officer**

**C. A. Keeney**
**Executive Director**

## ADMINISTRATIVE INFORMATION

This report was prepared for the Office of Naval Research (ONR) by the ISR/IO Department (Code 56), SPAWAR Systems Center Pacific, San Diego, CA. The project is funded by the Naval Innovative Science and Engineering (NISE) Program as a Basic Research project.

Released by
M. D. Osburn, Head
Electromagnetics Technology
Branch

Under authority of
J. McGee, Head
SoS & Platform Design
Division

# EXECUTIVE SUMMARY

A two- and four-horizontal dipole array is used to achieve higher efficiency and vertical gain for several conductivies. These designs are compared to a single horizontal dipole. The four-horizontal dipole array can be pointed 34º away from the vertical. The efficiency was reduced by only 1 dB. The surface wave was computed for all of the designs. The peak magnitude of the surface wave does explain the improved antenna efficiency.

# CONTENTS

## Figures

## Tables

# INTRODUCTION

The typical high-frequency (HF) communication monopole has a dipole pattern. The vertical null in the antenna pattern precludes significant HF reflections from the ionosphere to the region close to the antenna. A horizontal dipole at ¼ wavelength above ground could be used. However, the height of the dipole over ground is impractical at most HF frequencies. Placing the horizontal dipole closer to ground increases ground loss; part of this loss is the surface wave. For instance, A. Shahvarpour, A. A. Melcon, and C. Caloz [1] show that the surface wave loss depends on the dielectric modes of the slab . In contrast, the surface wave on a conducting medium does not have modes; however, the surface wave can be reduced with interference between dipoles in an array. P. L. Tokarsky and Yu A. Panchenko [2] discuss a vertical array of four dipoles over ground. This array was evaluated at 6 MHz with $\lambda/2$ spacing between elements, with the first element at $\lambda/4$ above ground or 112.5 m in height where $\lambda$ is the wavelength. They did not discuss the impact of interference on the surface wave. The interference in the array pattern and surface waves are discussed in detail.

In Section 2, EZNEC-Pro4® is used to model a 2-MHz horizontal dipole 1 m over ground. The worst performing HF frequency is 2 MHz; the height is $\lambda/150$ above ground[1]. The efficiency and gain will increase for higher HF frequencies. Computer Simulation Technology (CST) Microwave Studio® is used to compute the patterns for $\sigma = 0.1$. The efficiency, vertical gain, peak surface wave, impedance, and dipole length are calculated for several conductivities. The 2-MHz skin depth is calculated for the same conductivities. In Section 3, two dipoles are placed end to end with the feed points separated by $\lambda/2$ . This introduces an interference null on the axis of the dipoles. The efficiency, vertical gain, peak surface wave, impedance, and dipole length are calculated for several conductivities. In Section 4, a four-dipole array is analyzed and the efficiency, vertical gain, peak surface wave, impedance, and dipole length are calculated for several conductivities and for 1-m height. The geometry was selected to minimize the side lobes when the antenna beam is pointed. In Section 6, the antenna is pointed by modifying the input voltage phase. The efficiency, vertical gain, peak surface wave, and impedance are calculated for one conductivity at different input phase shifts.

The results for the other conductivities are summarized for the $\pm 70^\circ$ input phase. Section 7 is the conclusion.

# HORIZONTAL DIPOLE

The antenna pattern of a dipole in free space is very different than a dipole over real ground. The dipole in free space has a null along the axis of the dipole. A horizontal dipole over perfect ground requires an image dipole to meet the perfect ground boundary condition ($E_{\parallel} = 0$); the horizontal dipole over perfect ground does not have a surface wave (null at 0º elevation). The coordinate system used in this report puts (perfect) ground interface at $z = 0$, region $z > 0$ is free space, and region $z \le 0$ is real ground where $\varepsilon_r = 10$ with a range on conductivities. All dipole antennas in this report are parallel to the x-axis. For all of the models, the wire is perfectly conducting with a 2-mm diameter. The antenna length is adjusted to create a resonance at 2 kHz. The NEC4 double precession was used as the computational engine with a constant segment length that is 6 cm.

If the ground has a finite conductivity, the null at 0º elevation is no longer present; this null is reduced to a null in the y-axis direction. Figure 1 is the CST Microwave Studio directivity for $(\sigma = 0.1)$. The NEC and CST efficiency and directivity agree within 0.3 dB. The CST impedance,

---

[1] The design can be scaled by a factor $s$, where $f' = sf$ , $\sigma' = s\sigma$ , $r' = r/s$ , $h' = h/s$ , and $l' = l/s$ .

30.1 + j0.18, also agrees with NEC. Figure 2 shows the EZNEC surface wave at 1 km with the null in the y-axis direction. The horizontal dipole was evaluated at 1-m height above ground with several conductivities (Table 1). The efficiency increases with lower conductivity and larger skin depth (Table 2). The surface conductivity can be approximate with the quantity $\sigma\delta$ . The surface conductivity is unchanged for $\sigma \leq 0.001$; likewise, the efficiency remains the about the same. On the other hand, the surface wave is decreased for $\sigma \leq 0.001$. The surface wave is not a significant source of the loss.

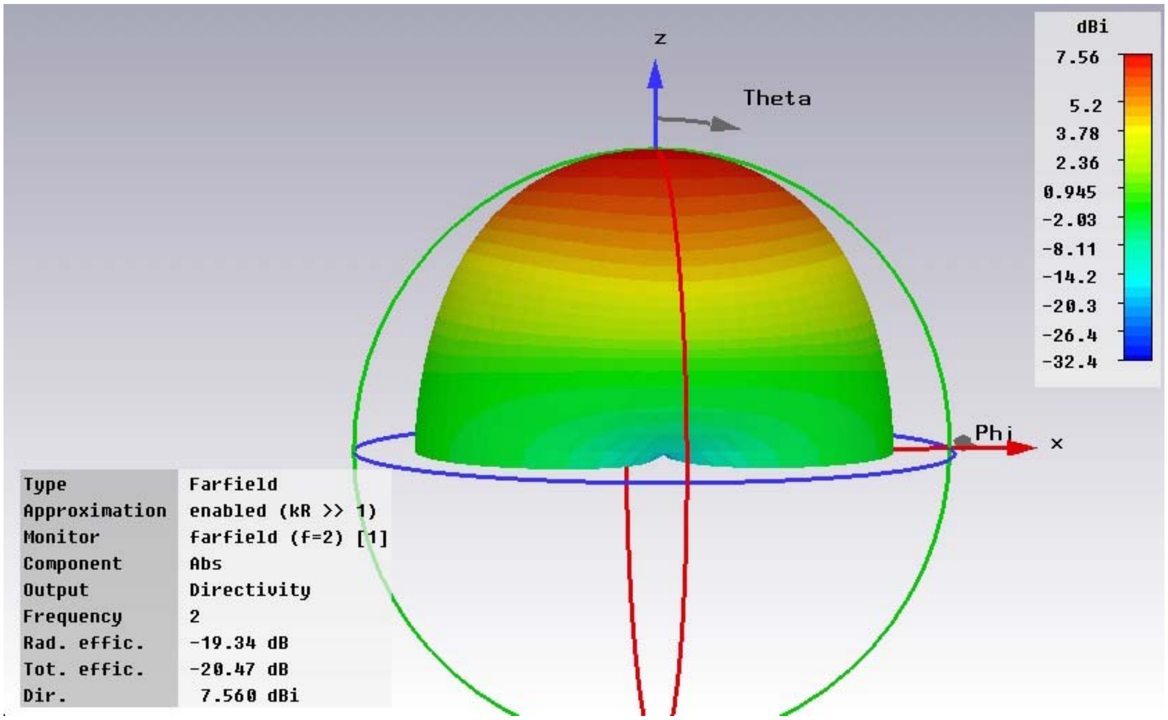
The perfect ground case is computed for reference.

Table 1. Horizontal dipole height of 1 m.

| Conductivity ($\sigma$) | Efficiency (dB) | Peak Gain (dB) | Peak Directivity Gain (dBi) | Peak SW (1 km in dB) | Z (Ω) | Length (m) |
|---|---|---|---|---|---|---|
| Perfect | 0 | 9.03 | 9.03 | 0 | 0.105 - $j$ 0.93 Ω | 74.58 |
| 0.1 | -19.62 | -11.86 | 7.76 | -20.30 | 31.8 + $j$ 0.118 | 70.30 |
| 0.01 | -16.27 | -9.34 | 6.93 | -14.14 | 57.3 - $j$ 1.29 | 69.66 |
| 0.001 | -13.58 | -6.83 | 6.75 | -17.23 | 103.5 - $j$ 0.58 | 68.46 |
| 0.0001 | -13.25 | -6.57 | 6.68 | -19.76 | 109.1 - $j$ 0.84 | 68.58 |

Table 2. Skin depth.

| Conductivity ($\sigma$) | Skin Depth ($\delta$) | Surface Conductivity ($\sigma\delta$) |
|---|---|---|
| $\frac{1}{\Omega m}$ | m | $\Omega^{-1}$ |
| 0.1000 | 3.76 | 0.3760 |
| 0.0010 | 168 | 0.1680 |
| 0.0001 | 1677 | 0.1677 |



| | |
|---|---|
| Type | Farfield |
| Approximation | enabled (kR >> 1) |
| Monitor | farfield (f=2) [1] |
| Component | Abs |
| Output | Directivity |
| Frequency | 2 |
| Rad. effic. | -19.34 dB |
| Tot. effic. | -20.47 dB |
| Dir. | 7.560 dBi |

Figure 1. The dipole pattern for $\sigma$ = 0.1.

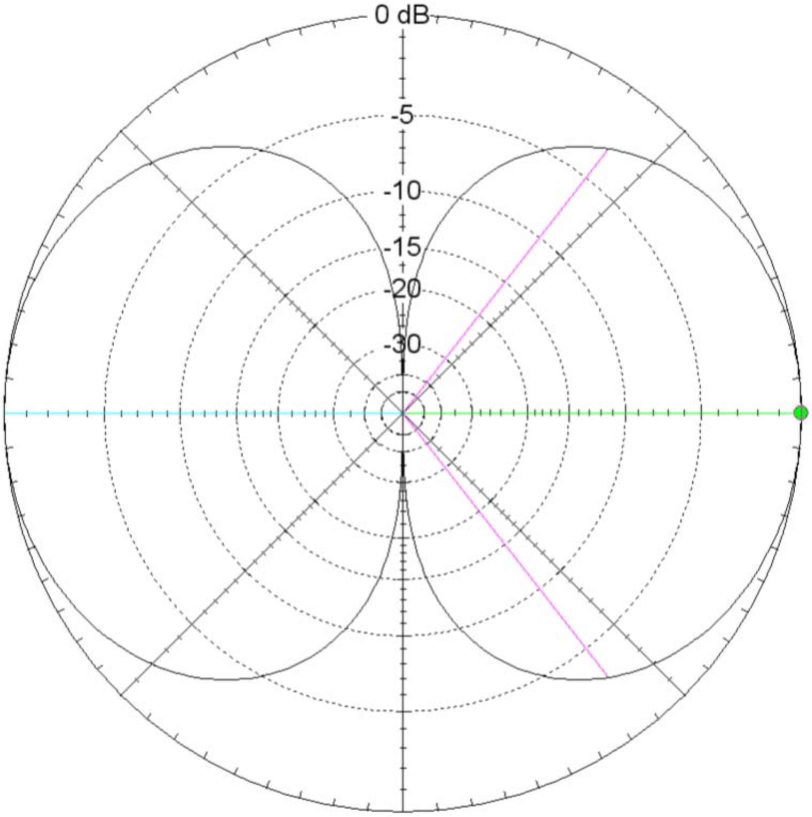


Figure 2. The dipole surface wave $\sigma$ = 0.01 where the outer ring is -14.14 dB.

# TWO-DIPOLE ARRAY

The gain in an antenna array pattern is caused by the interference of the radiation in the far field. The total energy radiated from the antenna is a constant; the destructive interference removes energy from one part of the pattern and constructive interference adds energy to a different part of the pattern. The largest gain in the x-y plane is on the axis of the dipole. Figure 3 shows two dipoles placed end to end with a feed point separation of $\lambda/2$. The dipoles will strongly interfere along the x-axis of the dipoles (Figure 4). The simulation results are presented in Table 3. The CST pattern for $\sigma = 0.1$ is shown in Figure 4 and the EZNEC surface wave pattern in shown in Figure 5; note the additional null in the surface wave pattern. The end-to-end dipole increases the efficiency by a fraction of 1 dB. The peak directivity is improved by about 2.2 dB. The peak gain is increased by 3 dB. The surface wave for the two-dipole array was reduced by 4.3 dB. In addition, for $\sigma \le 0.001$ the efficiency is about the same, but the surface wave is still decreasing. This is the same data pattern seen in the single-dipole case. The surface wave is not a significant source of the loss.

A. Rodriguez and L. Koyama[2] modeled the parallel array of horizontal dipoles. The improvement in the array gain was insignificant. The interference in the y-direction deepens the null; this has a small impact on the pattern. On the other hand, two parallel dipoles in free space with a $\lambda/2$ separation will destructively interfere in the plane of the dipoles and constructively interference normal to the plane of the dipoles. The free space gain is increased by 3 dB. Peder Hansen[3] predicted that the efficiency of the parallel dipole increases as the dipole spacing $< \lambda/2$ is reduced. The improved efficiency and directivity gain cancel to yield an almost flat peak gain over a wide range of dipole spacing.

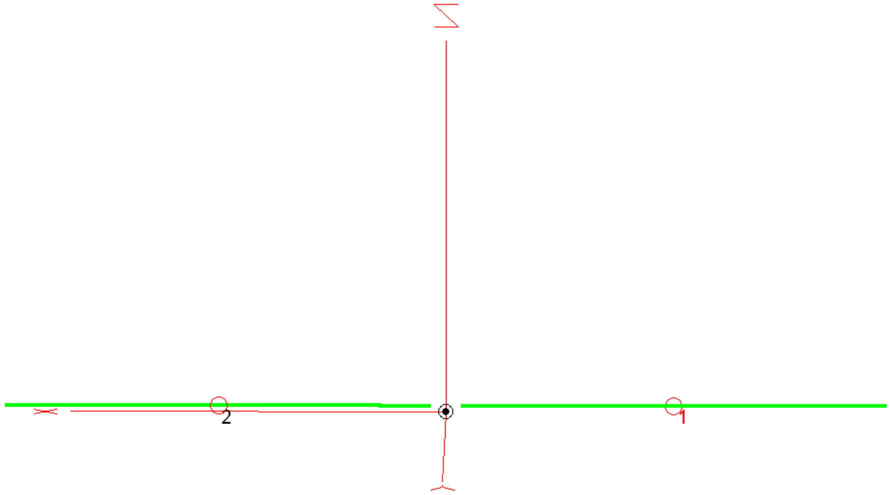


Figure 3. EZNEC-Pro-4 illustration of the end-to-end dipole.

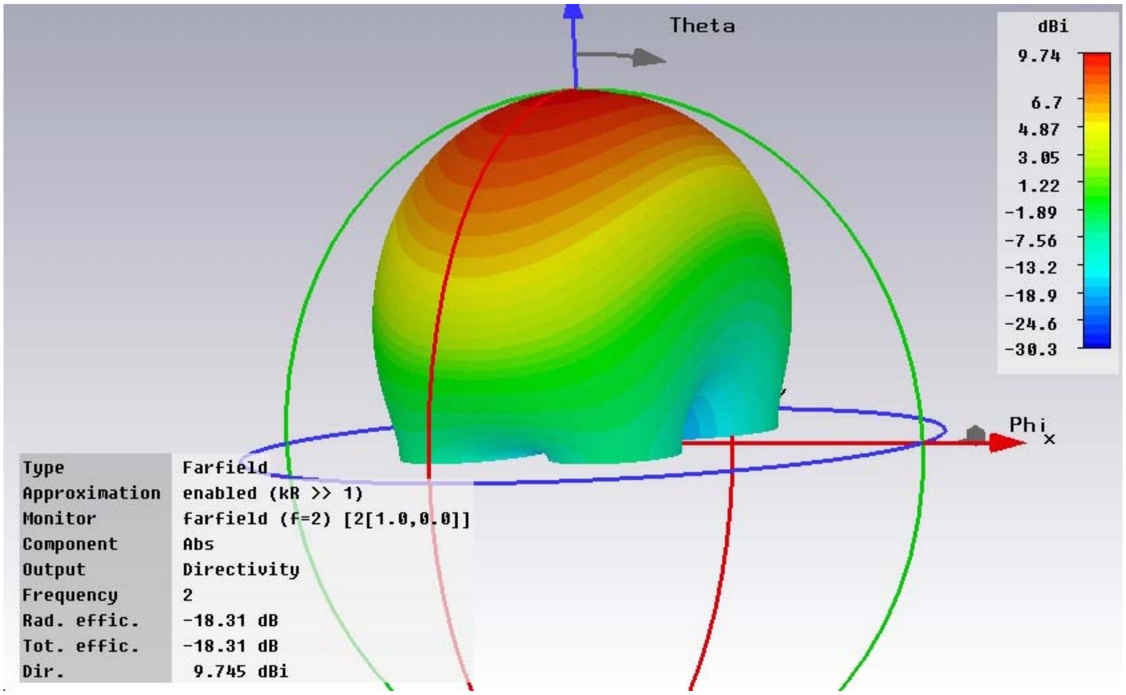
---

[2] Alberto Rodriguez and Lance Koyama, personal communication

[3] Peder Hansen, personal communication

Table 3. Stimulation results.

| Conductivity (m/Ω) | Efficiency (dB) | Peak Gain (dB) | Peak Isotropic Gain (dBi) | Peak SW (1 km in dB) | Z (Ω) | Length (m) |
|---|---|---|---|---|---|---|
| 0.1000 | -18.58 | -8.86 | 9.72 | -24.68 | 31.9 + $j$ 0.58 | 72.30 |
| 0.0100 | -15.59 | -6.31 | 9.28 | -18.51 | 57.0 - $j$ 0.86 | 69.66 |
| 0.0010 | -12.86 | -3.82 | 9.04 | -21.7 | 103.5 - $j$ 0.81 | 68.34 |
| 0.0001 | -12.57 | -3.63 | 8.94 | -24.23 | 111.0 + $j$ 1.15 | 68.58 |



```
Type            Farfield
Approximation   enabled (kR >> 1)
Monitor         farfield (f=2) [2[1.0,0.0]]
Component       Abs
Output          Directivity
Frequency       2
Rad. effic.     -18.31 dB
Tot. effic.     -18.31 dB
Dir.             9.745 dBi
```

Figure 4. The directivity of the end-to-end dipoles shows a deep null ($\sigma$ = 0.1).

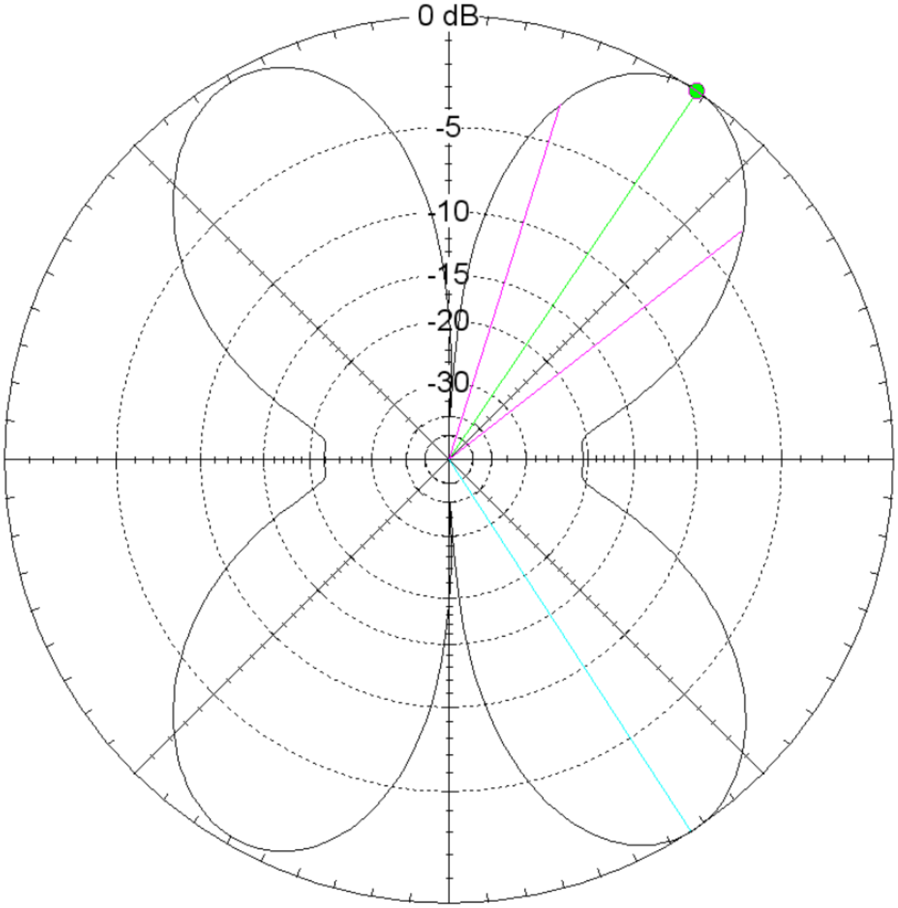


Figure 5. The surface wave for the end-to-end dipoles with $\sigma = 0.1$.

## FOUR-DIPOLE ARRAYS

Symmetry of the four-dipole arrangement limits the geometry of four-dipole arrays. One option, two parallel end-to-end dipoles, has limited design flexibility. The only dimension that can be changed is the spacing of the two parallel end-to-end dipoles. The other option is the geometry in Figure 6. The spacing between the feed point of dipoles 2 and 3 can adjusted from $\lambda / 2$ to $\lambda$. The spacing between the feed point of dipoles 1 and 4 can adjusted from $\lambda / 1000$ to $\lambda$. When the spacing is $\lambda$ between the dipoles, the interference is along the x- and y-axis directions. If the spacing between the dipoles is reduced to $\lambda / \sqrt{2}$, the distance between adjacent dipoles is $\lambda / 2$. The interference is along the diagonal. The spacing between dipoles 1 and 4 was reduced to optimize the directivity pattern in the next section.

In Figure 6, the spacing between the dipoles 2 and 3 feed points is 105.96 m and the spacing between the dipoles 1 and 4 feed points is 35 m. The height of the wires over ground is 1 m. Table 4 shows the efficiency, vertical gain, impedance, and antenna length. The antenna length was adjusted to move the resonant frequency to 2 MHz. The efficiency of the four-dipole array is 2.6 to 3 dB higher than the two-dipole array; the peak directivity is increased by only 0.2 dB. The peak gain increased by 2.8 to 3 dB. In this case, the surface wave is increased by 2 to 3.4 dB. The surface wave amplitude is not correlated with efficiency. The surface wave plays an insignificant role in the efficiency.

Figures 7 and 8 show the CST directivity pattern for $\sigma = 0.1$. The surface wave plot in Figure 9 shows a deep null on the x-axis. The y-axis has a small null. The CST directivity and NEC have a 0.03 dBi difference. The efficiencies differ by 0.27 dB. Figure 9 shows the EZNEC surface wave calculation.

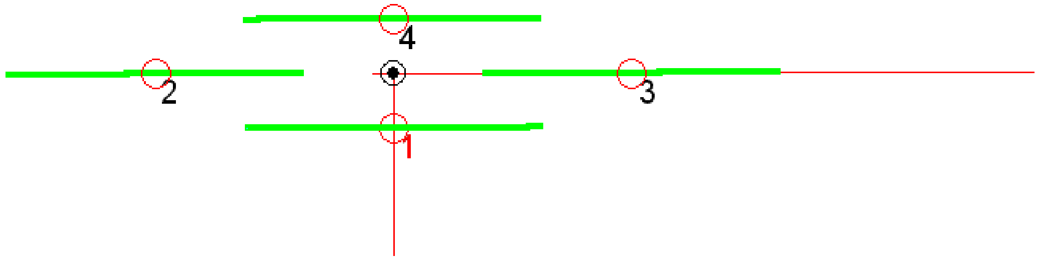
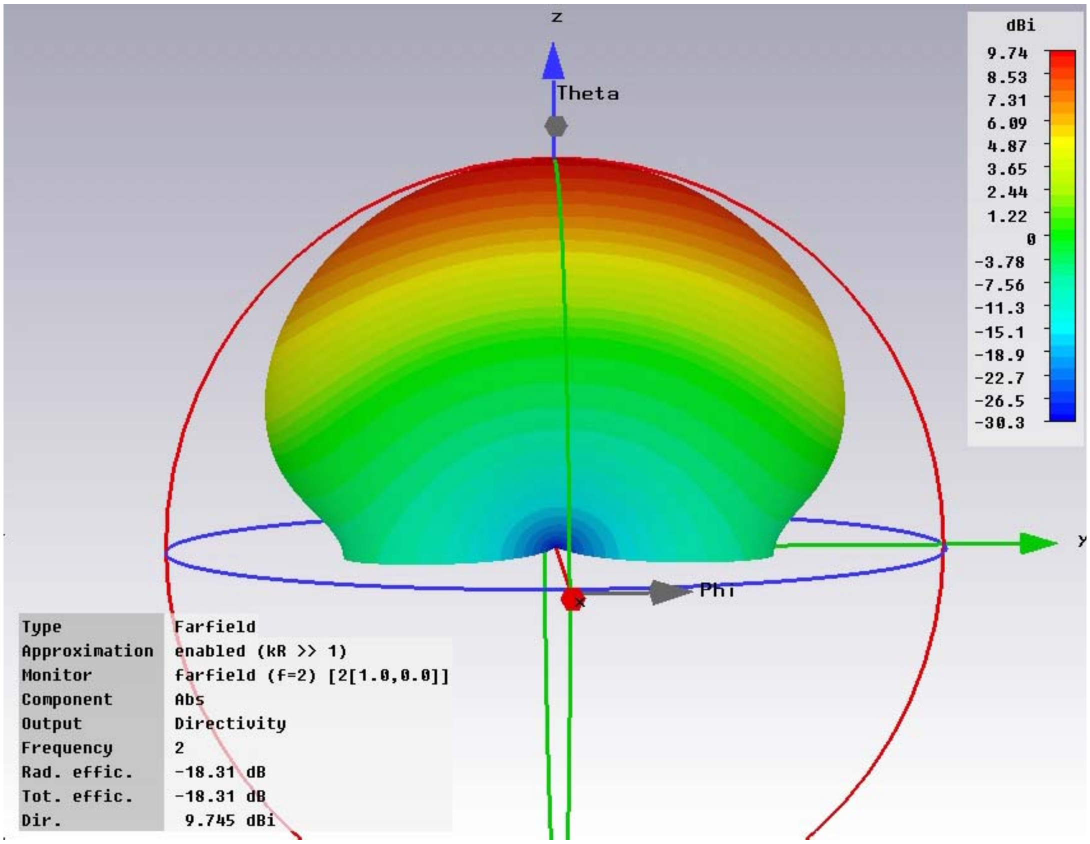


Figure 6. EZNEC illustration of four dipoles 1 m above ground. The antenna is viewed from above.

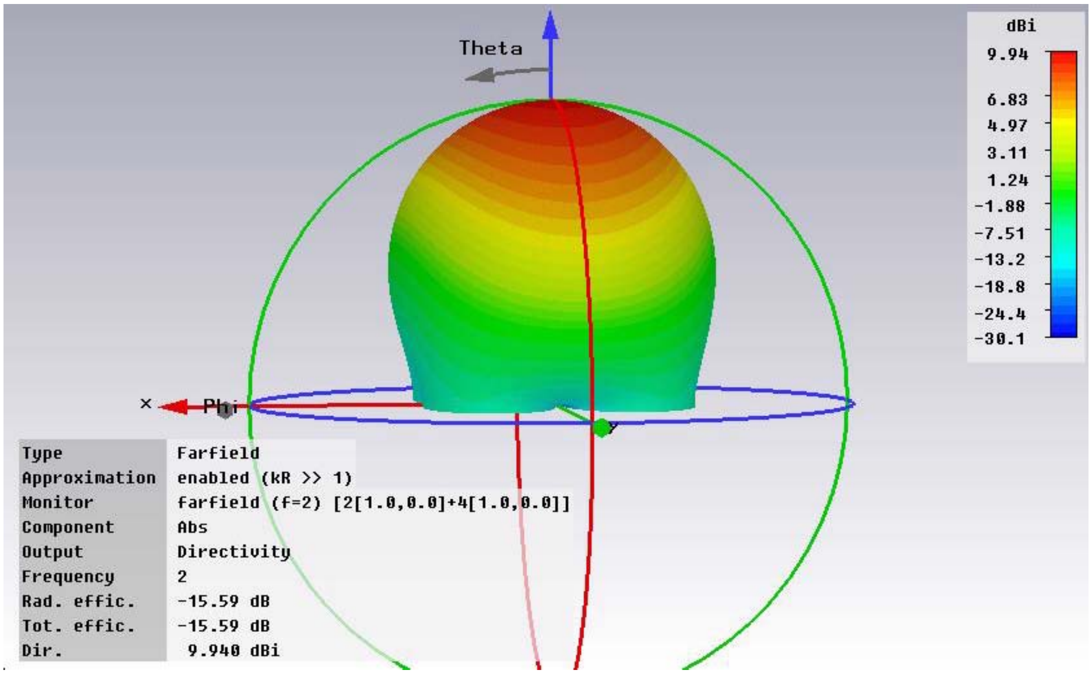
Table 4. Dipole height of 1 m.

| $\sigma$ (m/Ω) | Efficiency (dB) | Peak Gain (dB) | Peak Isotropic Gain (dBi) | Peak SW (1 km in dB) | Z for 1 & 4 (Ω) | Z for 2 & 3 (Ω) | Length (m) |
|---|---|---|---|---|---|---|---|
| 0.1 | -15.86 | -5.95 | 9.91 | -22.98 | 32.68 - $j$ 1.76 | 32.22 - $j$ 1.73 | 72.18 |
| 0.01 | -12.91 | -3.45 | 9.46 | -16.94 | 58.39 + $j$ 1.81 | 58.39 + $j$ 1.61 | 69.78 |
| 0.001 | -10.22 | -0.60 | 9.21 | -20.23 | 109.2 - $j$ 3.26 | 107.4 - $j$ 12.69 | 69.40 |
| 0.0001 | -9.58 | -0.60 | 8.98 | -22.21 | 122.5 + $j$ 8.24 | 100.8 + $j$ 14.97 | 69.30 |



Type Farfield
Approximation enabled (kR >> 1)
Monitor farfield (f=2) [2[1.0,0.0]]
Component Abs
Output Directivity
Frequency 2
Rad. effic. -18.31 dB
Tot. effic. -18.31 dB
Dir. 9.745 dBi

Figure 7. The pattern for the four-dipole array where $\sigma$ = 0.1 when viewed from the x-axis.



Type Farfield
Approximation enabled (kR >> 1)
Monitor farfield (f=2) [2[1.0,0.0]+4[1.0,0.0]]
Component Abs
Output Directivity
Frequency 2
Rad. effic. -15.59 dB
Tot. effic. -15.59 dB
Dir. 9.940 dBi

Figure 8. The pattern for the four-dipole array where $\sigma$ = 0.1 when viewed from the y-axis.

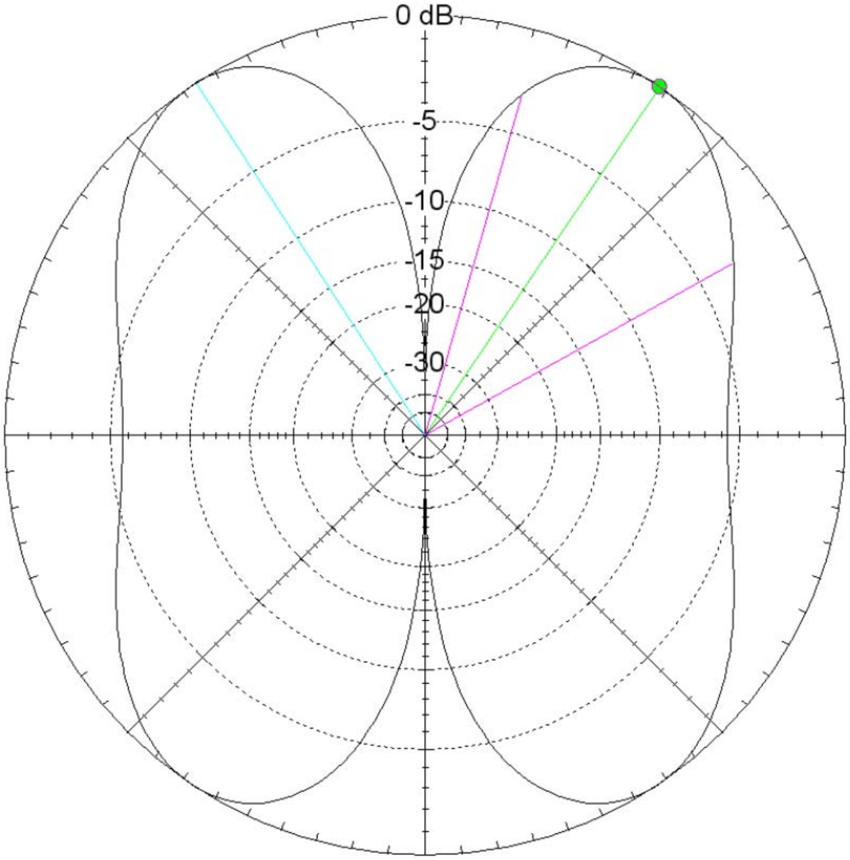


Figure 9. The surface wave for the four-dipole array where $\sigma$ = 0.1.

## DIRECTIONAL NVIS ANTENNA

The antenna pattern can be pointed in the x-direction by applying a phase $\theta$ to dipole 2 and a phase $-\theta$ to dipole 3 in Figure 6. The antenna parameters for $\sigma = 0.01$ and a range of angles $\theta$ listed in Table 5 are efficiency, peak gain, angle of peak gain, peak surface wave, and typical impedance.  Dipole 3 and 4 have different impedances; only one is given in column 6. A $\pm 70^\circ$ input phase shift will point the pattern $24^\circ$ off vertical or at $66^\circ$ elevation with only a 1-dB loss in gain and efficiency. The impedance in Table 5 has a very small variation.

Table 6 computes the dipole array performance for $\pm 70$ phase and a range of conductivities. CST was used to model the antenna with ground conductivity $\sigma = 0.1$. In Figure 10, the 3-D (three-dimensional) antenna pattern is rotated to show the very small (-20 dBi) side lobes of the antenna. In Figure 11, the 3-D antenna pattern is viewed from the side to show the small null on the y-axis. The 3-dB width of elevation cut is 49.4º (Figure 12). Figure 13 is the surface wave amplitude in dB at 1 km. Pointing the beam 24º  to the side reduced the efficiency and gain by about 1 dB. The peak surface wave is increased by a much larger 6.65 dB.

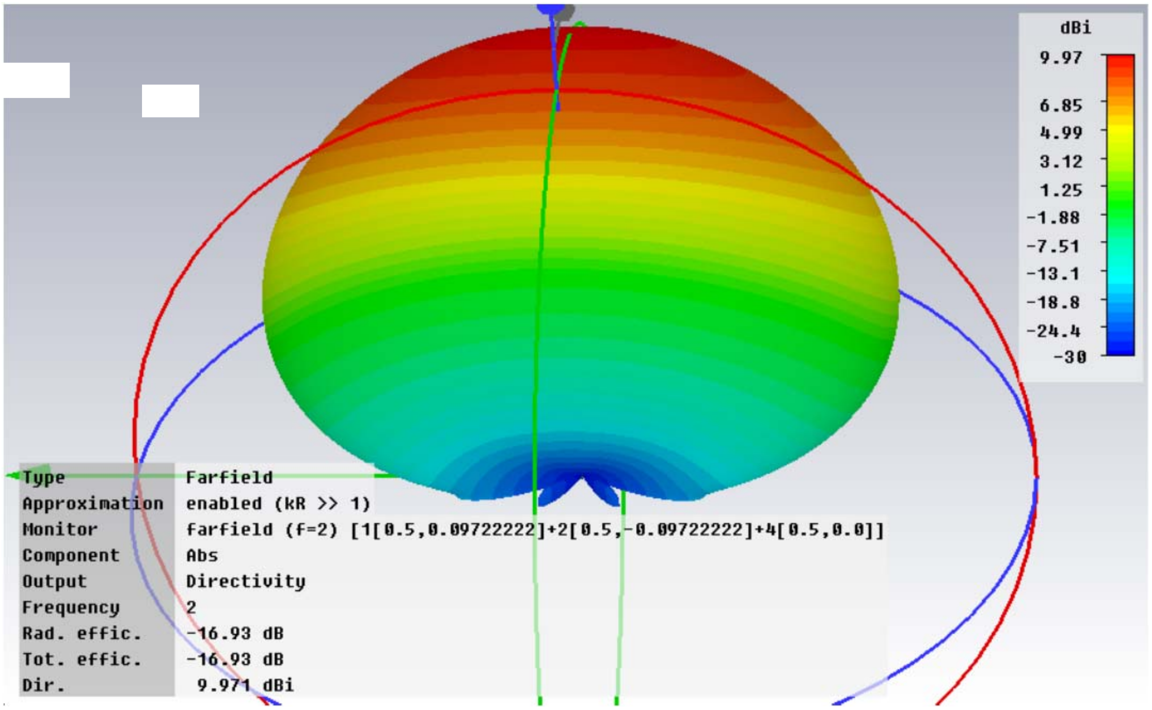
The variation in impedance between 0º to 70º phase is small for $\sigma \geq 0.01$, with only a small percentage change in the feed point reflection. A change in pointing angle would not require retuning. The EZNEC and CST directives agree within 0.03 dB, and the efficiency differs by 0.36 dB.

Table 5. Directivity for $\sigma$ = 0.01.

| Phase (˚) | Efficiency (dB) | Peak Gain (dB) | Angle (˚) | Peak SW (1-km dB) | Z for 2 or 3 C (Ω) | Z for 1 or 4 S Ω |
|---|---|---|---|---|---|---|
| 0 | -12.91 | -3.45 | 90 | -16.94 | 58.39 + $j$ 1.81 | 58.4 + $j$ 1.81 |
| 10 | -12.93 | -3.46 | 87 | -15.72 | 58.24 + $j$ 1.96 | 60.2 + $j$ 0.37 |
| 20 | -12.99 | -3.52 | 84 | -14.60 | 58.07 + $j$ 2.07 | 60.1 + $j$ 0.37 |
| 30 | -13.10 | -3.62 | 81 | -13.58 | 57.9 + $j$ 2.13 | 60.1 + $j$ 0.35 |
| 40 | -13.24 | -3.75 | 78 | -12.65 | 57.73 + $j$ 2.14 | 59.95 + $j$ 0.33 |
| 50 | -13.44 | -3.92 | 72 | -11.79 | 57.58 + $j$ 2.13 | 59.8 + $j$ 0.31 |
| 60 | -13.69 | -4.12 | 69 | -11.01 | 57.45 + $j$ 2.08 | 59.7 + $j$ 0.29 |
| 70 | -13.99 | -4.37 | 66 | -10.29 | 57.35 + $j$ 2.03 | 59.6 + $j$ 0.26 |
| 80 | -14.36 | -4.65 | 63 | -9.63 | 57.27 + $j$ 1.97 | 59..4 + $j$ 0.23 |
| 90 | -14.79 | -4.98 | 60 | -9.04 | 57.21 + $j$ 1.91 | 59.2 + $j$ 0.20 |
| 100 | -15.29 | -5.36 | 57 | -8.58 | 57.16 + $j$ 1.87 | 59.1 + $j$ 0.17 |
| 110 | -15.86 | -5.78 | 51 | -8.26 | 57.12 + $j$ 1.82 | 58.9 + $j$ 0.15 |
| 120 | -16.50 | -6.25 | 48 | -8.08 | 57.07 + $j$ 1.79 | 58.8 + $j$ 0.12 |

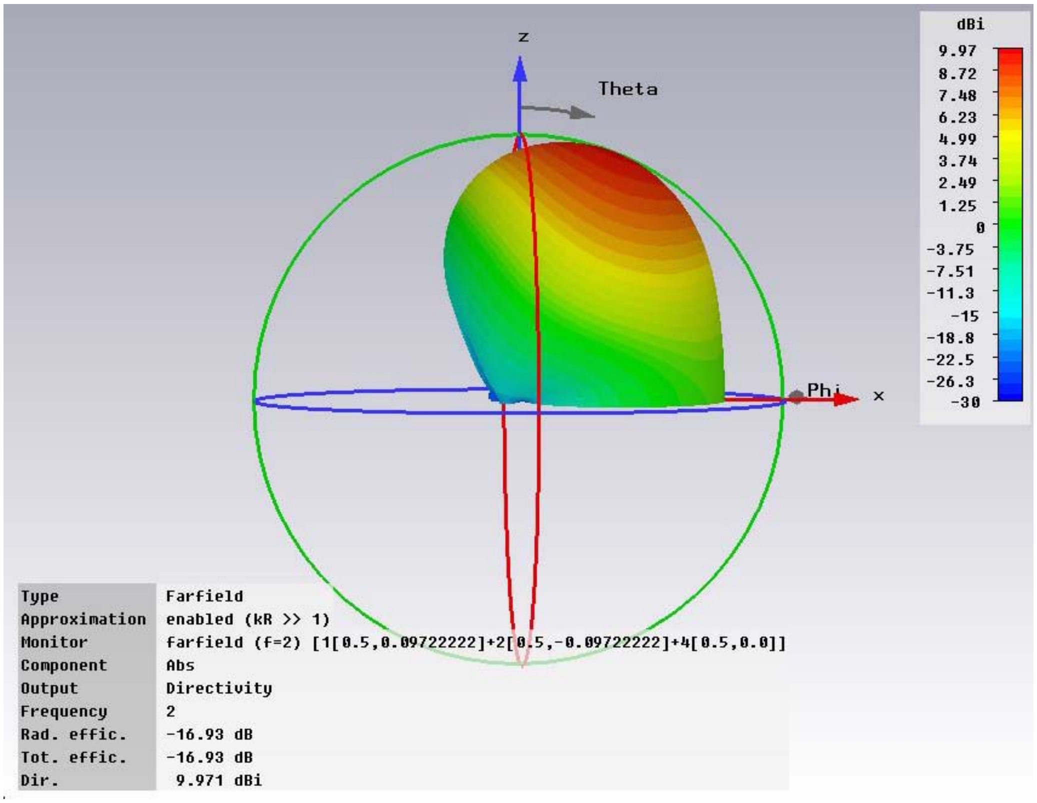
Table 6. Input with ±70º phase.

| $\sigma$ | Efficiency (dB) | Peak Gain (dB) | Angle (º) | Peak SW (1 km in dB) | Z for 2 or 3 C (Ω) | Z for 1 or 4 S (Ω) |
|---|---|---|---|---|---|---|
| 0.1 | -17.29 | -7.24 | 69 | -16.44 | 3.31 - $j$ 1.67 | 32.3 - $j$ 2.16 |
| 0.01 | -13.99 | -4.37 | 66 | -10.29 | 57.4 + $j$ 2.03 | 59.6 + $j$ 0.26 |
| 0.001 | -11.30 | -1.73 | 66 | -13.35 | 104 + $j$ 0.2615 | 105.3 - $j$ 7.37 |
| 0.0001 | -10.63 | -1.25 | 66 | -15.43 | 119.9 + $j$ 24.7 | 98.5 - $j$ 9.62 |



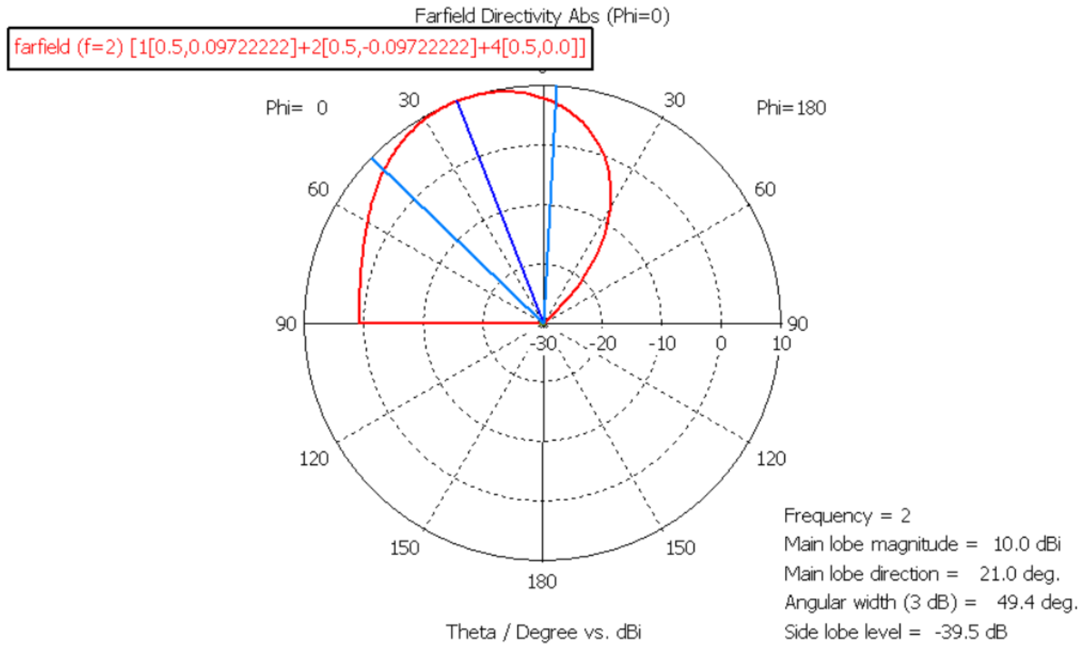
```
Type           Farfield
Approximation  enabled (kR >> 1)
Monitor        farfield (f=2) [1[0.5,0.09722222]+2[0.5,-0.09722222]+4[0.5,0.0]]
Component      Abs
Output         Directivity
Frequency      2
Rad. effic.    -16.93 dB
Tot. effic.    -16.93 dB
Dir.            9.971 dBi
```

Figure 10. Pattern pointed at 66º elevation. The two side lobes are small.



```
Type            Farfield
Approximation   enabled (kR >> 1)
Monitor         farfield (f=2) [1[0.5,0.09722222]+2[0.5,-0.09722222]+4[0.5,0.0]]
Component       Abs
Output          Directivity
Frequency       2
Rad. effic.     -16.93 dB
Tot. effic.     -16.93 dB
Dir.             9.971 dBi
```

Figure 11. Pattern pointed at 66º elevation.



```
Frequency = 2
Main lobe magnitude =   10.0 dBi
Main lobe direction =   21.0 deg.
Angular width (3 dB) =   49.4 deg.
Side lobe level =  -39.5 dB
```

Figure 12. Elevation slice on the x-axis. The -3-dB beam width is 56.2º.

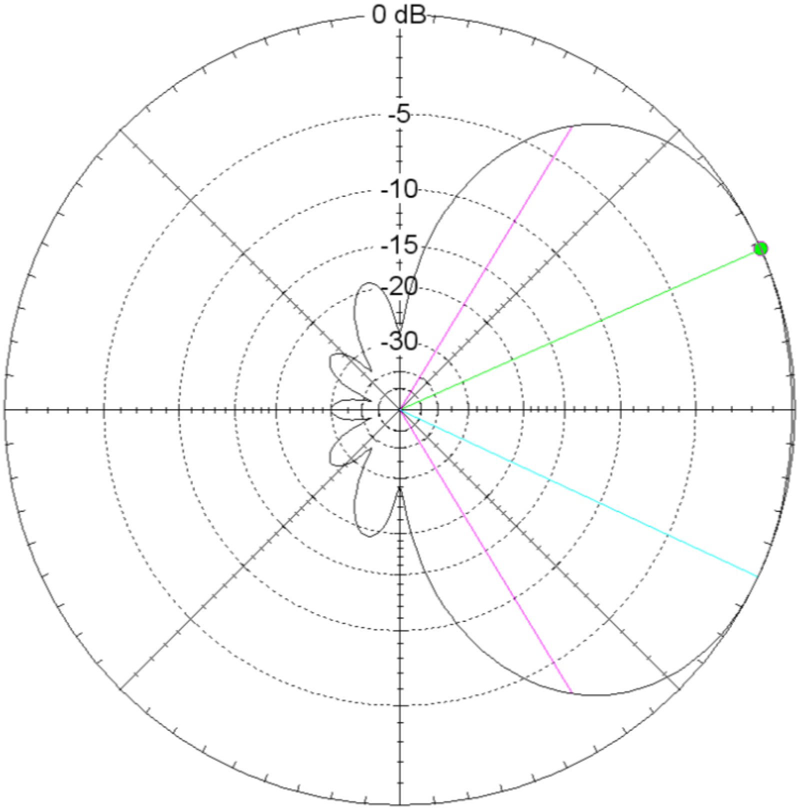


Figure 13. Surface wave of the directional antenna at 1 km and the 0-dB reference level is -9.63 dB.

## CONCLUSION

The null in a vertical monopole greatly reduces the signal available to ionospheric communication. Elevating a horizontal dipole $\lambda/4$ above ground is impractical for most HF frequencies. The two- and four-horizontal dipole arrays have about a 3 and 5.9 dB higher gain than the simple horizontal dipole, respectively. The NIVIS also can be pointed in one direction to allow better performance. Pointing the beam 24° off the vertical axis introduces a 1-dB efficiency reduction. The impedance is almost constant for a wide range of input phase shifts. Increasing the frequency or height will improve the performance. The improvement in efficiency is not correlated with the peak surface wave amplitude; the surface wave is not the primary loss mechanism.

## REFERENCES

1. A. Shahvarpour, A. A. Melcon, and C. Caloz. 2011. “Analysis of the Radiation Efficiency of a Horizontal Electric Dipole on a Grounded Dielectric Slab.” *2011 IEEE International Symposium on Antnnas and Propagation – Proceedings* (pp. 1293-1296). 3-8 July, Spokane, WA.

2. P. L. Tokarsky and A. P. Yu. 2007. “Modeling Dipole Antenna Arrays Placed Near to Interfaced Between Two Media.” *2007 International Conference on Antenna Theory and Techniques – Proceedings* (pp. 452-454). 17-21 December, Scvastropol, Ukraine.

# APPENDIX

The conventional calculation of skin effect [5] is modified for $\varepsilon_0 = 10$. The ground is a poor conductor; this correction is significant. The square of the index of refraction is

$$n^2 = 10 - j\frac{\sigma}{\varepsilon_0 \omega},$$

where $\omega$ is the angular frequency, $\sigma$ is conductivity, $\varepsilon_0 = 10^7 / 4\pi c^2$, and c is the speed of light. The propagation in the material decays as

$$e^{-kz * imag(n)}.$$

The skin depth is

$$\delta = \frac{c}{\omega * imag(n)}.$$

# REPORT DOCUMENTATION PAGE

*Form Approved*
*OMB No. 0704-01-0188*

**1. REPORT DATE** *(DD-MM-YYYY)*
September 2013

**2. REPORT TYPE**
Final

**3. DATES COVERED** *(From - To)*

**4. TITLE AND SUBTITLE**

Directional Array for Near Vertical Incident Skywave (NVIS)

**5a. CONTRACT NUMBER**

**5b. GRANT NUMBER**

**5c. PROGRAM ELEMENT NUMBER**

**5d. PROJECT NUMBER**

**5e. TASK NUMBER**

**5f. WORK UNIT NUMBER**

**6. AUTHORS**

Thomas O. Jones III

**7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)**

SSC Pacific, 5622 Hull Street, San Diego, CA 92152–5001

**8. PERFORMING ORGANIZATION REPORT NUMBER**

TR 2027

**9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)**

Office of Naval Research
Naval Innovation Science and Engineering (NISE) Program
One Liberty Center
875 N. Randolph Street, Suite 1425
Arlington, VA 22203-1995

**10. SPONSOR/MONITOR'S ACRONYM(S)**
ONR NISE

**11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

**12. DISTRIBUTION/AVAILABILITY STATEMENT**

Approved for public release.

**13. SUPPLEMENTARY NOTES**

This is work of the United States Government and therefore is not copyrighted. This work may be copied and disseminated without restriction.

**14. ABSTRACT**

A two- and four-horizontal dipole array is used to achieve higher efficiency and vertical gain for several conductivies. These designs are compared to a single horizontal dipole. The four-horizontal dipole array can be pointed 34º away from the vertical. The efficiency was reduced by only 1 dB. The surface wave was computed for all of the designs. The peak magnitude of the surface wave does explain the improved antenna efficiency.

**15. SUBJECT TERMS**

| | | | |
|---|---|---|---|
| horizontal dipole | directional antennas | planar array | antenna radiation pattern |
| surface wave | phased array | transmitting antenna | antenna radiation |

**16. SECURITY CLASSIFICATION OF:**

| a. REPORT | b. ABSTRACT | c. THIS PAGE | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES |
|---|---|---|---|---|
| U | U | U | U | 21 |

**19a. NAME OF RESPONSIBLE PERSON**
Thomas O. Jons III

**19B. TELEPHONE NUMBER** *(Include area code)*
(619) 553-7082

**Standard Form 298** (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

# INITIAL DISTRIBUTION

| | | |
|---|---|---|
| 84300 | Library | (2) |
| 85300 | Archive/Stock | (1) |
| 52260 | T. O. Jones III | (1) |

Defense Technical Information Center
Fort Belvoir, VA 22060–6218 (1)

SSC Pacific
San Diego, CA 92152-5001