

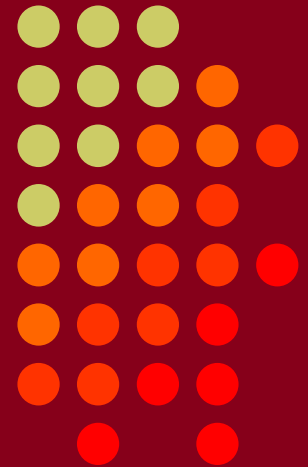
# Maximizing Performance of HF Antennas with Irregular Terrain

Jim Breakall  
WA3FET

Penn State University  
January 23, 2021

• CTU •  
CONTEST  
UNIVERSITY

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# HF Antennas in Irregular Terrain



- **How did it all start?**
- **Navy Helicopter Measurements in Utah**
- **Geometrical Theory of Diffraction (GTD-UTD)**
- **K6STI TA; N6BV VOACAP and HFTA**
- **K6TU Topography Service**
- **WP3R Contest Station at WA3FET KP4 Farm**
- **Magic Mountain – Camp Kilowatt in PA**
- **The Future – 3D Modeling??**

# SRI and Eyring Helicopter Measurements of HF Antenna Patterns in Irregular Terrain in Utah for Navy – Started Terrain Modeling for Ham Radio – TA and HFTA



# IEEE Transactions on Antennas and Propagation - 1994



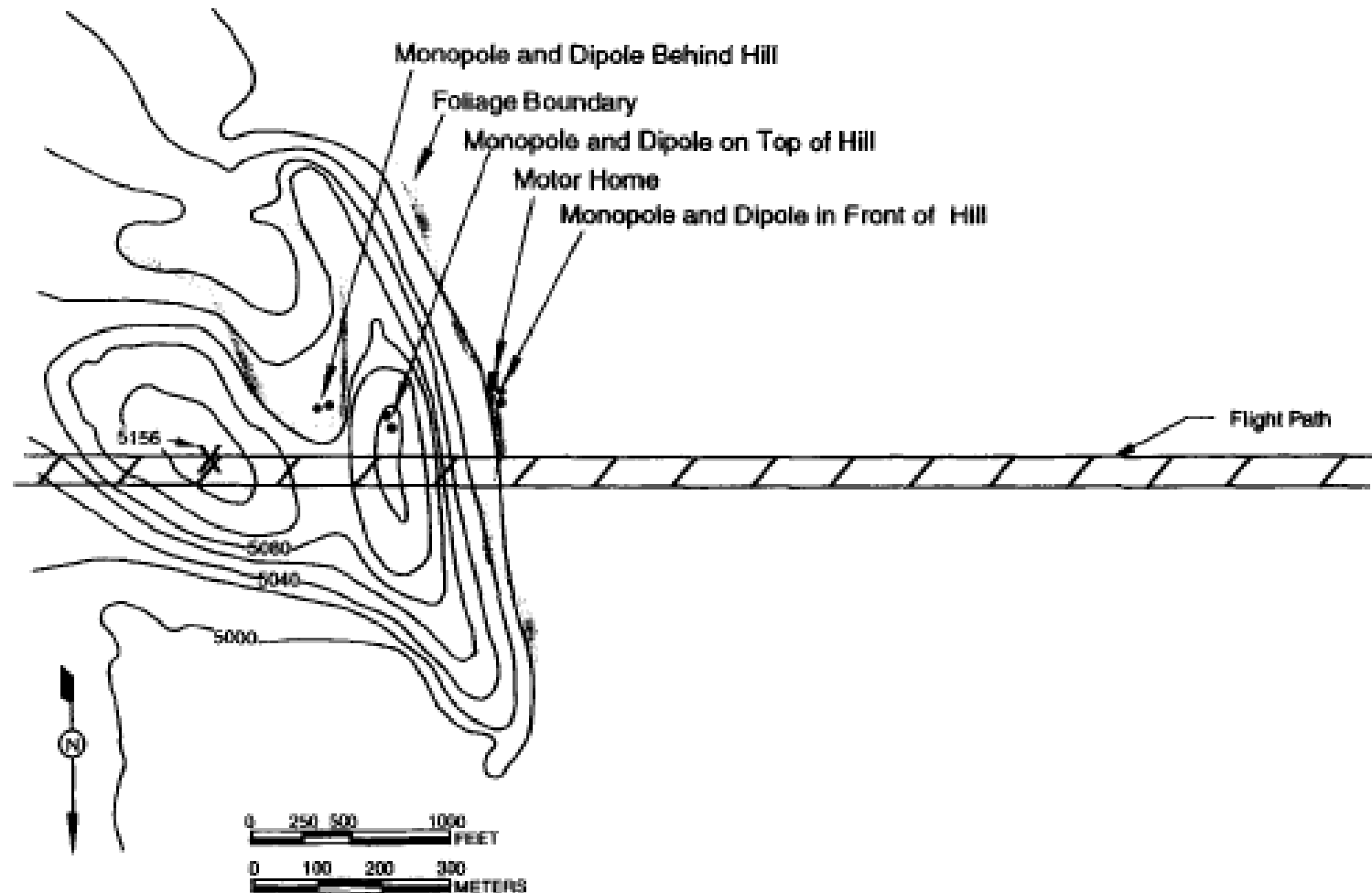
936

IEEE TRANSACTIONS ON ANTENNAS AND PROPAGATION, VOL. 42, NO. 7, JULY 1994

## The Modeling and Measurement of HF Antenna Skywave Radiation Patterns in Irregular Terrain

J. K. Breakall, *Member, IEEE*, J. S. Young, G. H. Hagn, *Fellow, IEEE*,  
R. W. Adler, *Member, IEEE*, D. L. Faust, *Member, IEEE*, and D. H. Werner, *Member, IEEE*

# Overview and Topography of Cedar Valley, UT, Test Area and Antenna Siting



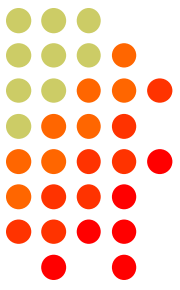
# Relative Permittivity (Dielectric Constant) and Conductivity of Earth Soil Measured



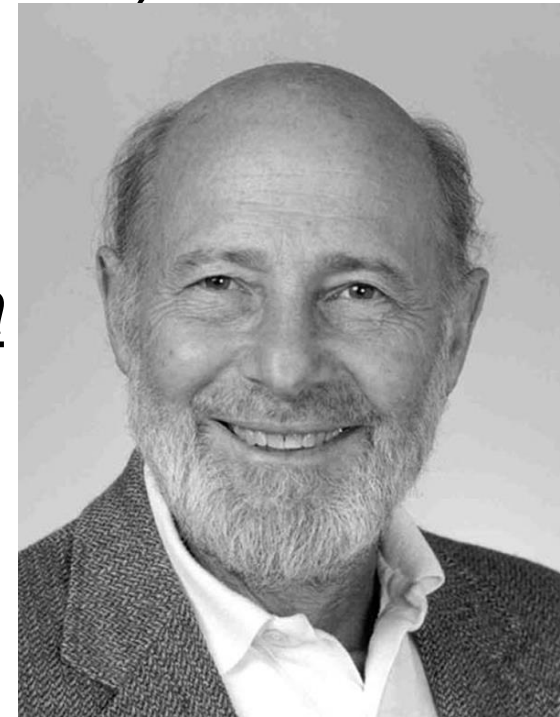
- **Ground Constants measured by SRI and Eyring with OWL and Inverted Monopole**

<b>Frequency (MHz)</b>	<b><math>\epsilon_r</math></b>	<b><math>\sigma</math> (mS/m)</b>
<b>8.0150</b>	<b>14.9</b>	<b>6.5</b>
<b>15.3415</b>	<b>11.7</b>	<b>9.3</b>
<b>27.7415</b>	<b>9.5</b>	<b>16.1</b>

# Geometrical Theory of Diffraction GTD



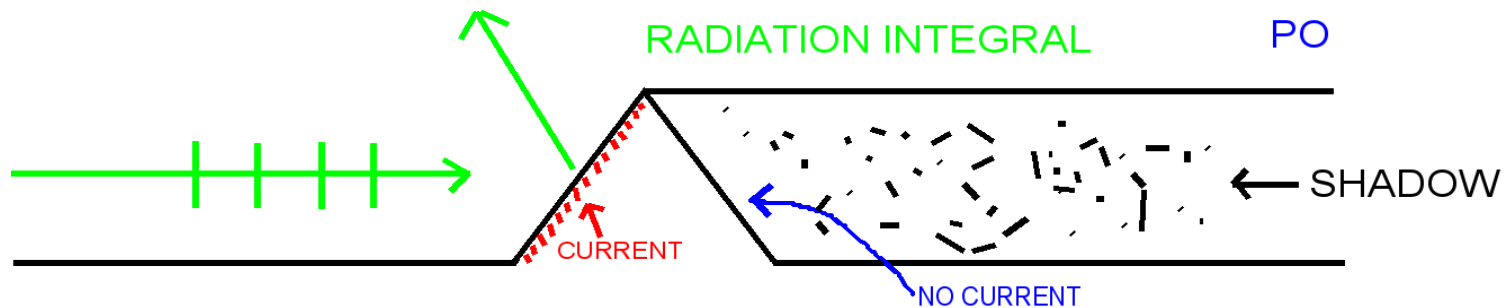
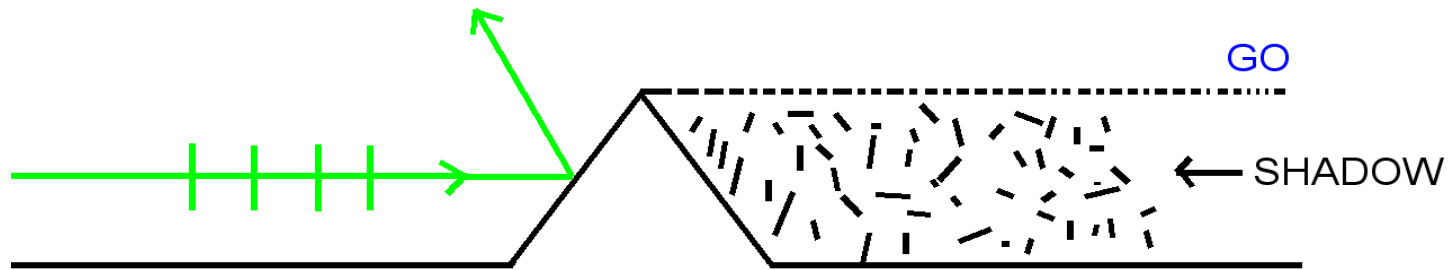
- Prof. Joseph Keller – Applied Mathematician
- Courant Institute of Mathematics (NYU)
- Stanford University
- *Geometrical theory of diffraction in*  
*Journal of Optical Society of America*  
1962
- Died in 2016 at Stanford, CA



# GTD Became the Improved Uniform Theory of Diffraction (UTD) at Ohio State University

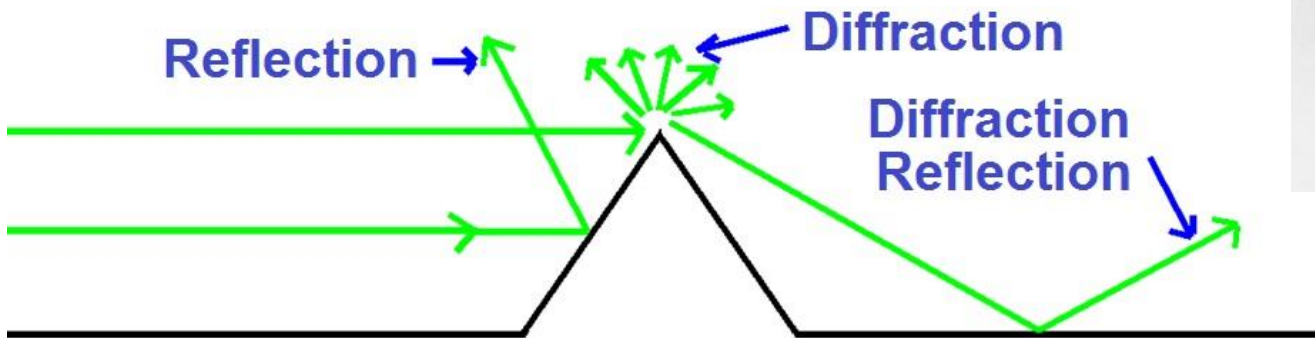
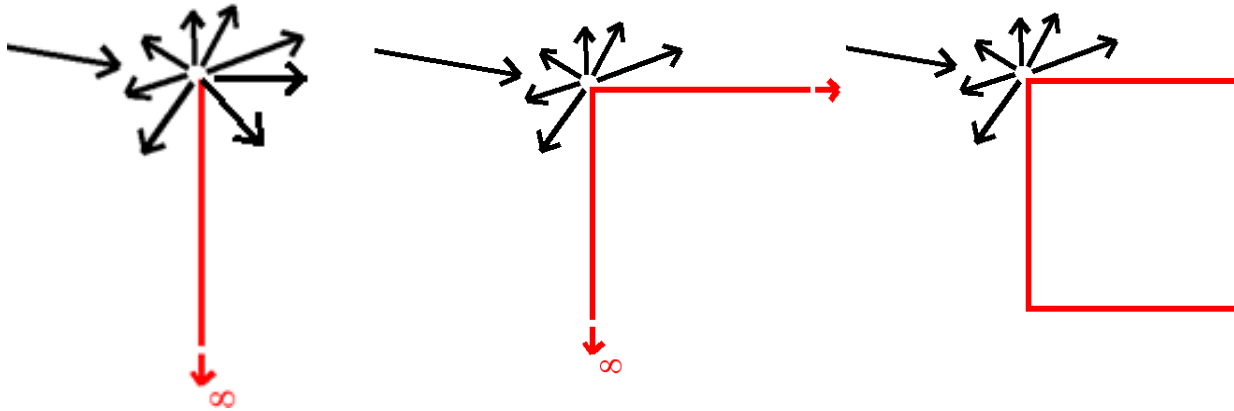


- Geometrical Optics (GO) – Ray Tracing
- Physical Optics (PO) – Current Induced

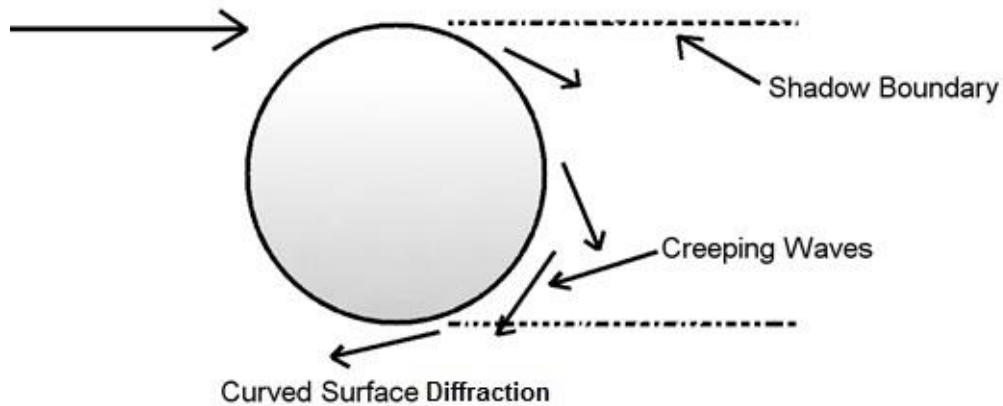
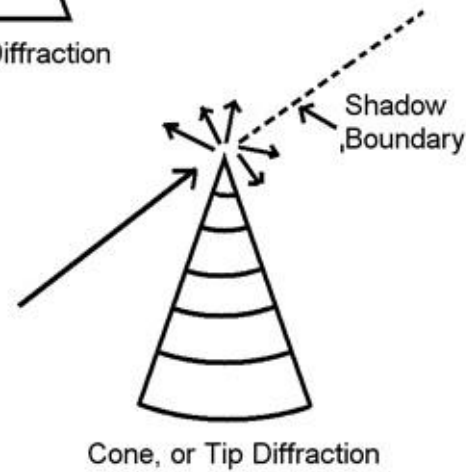
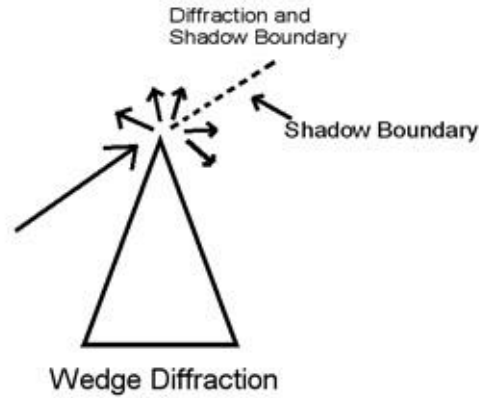




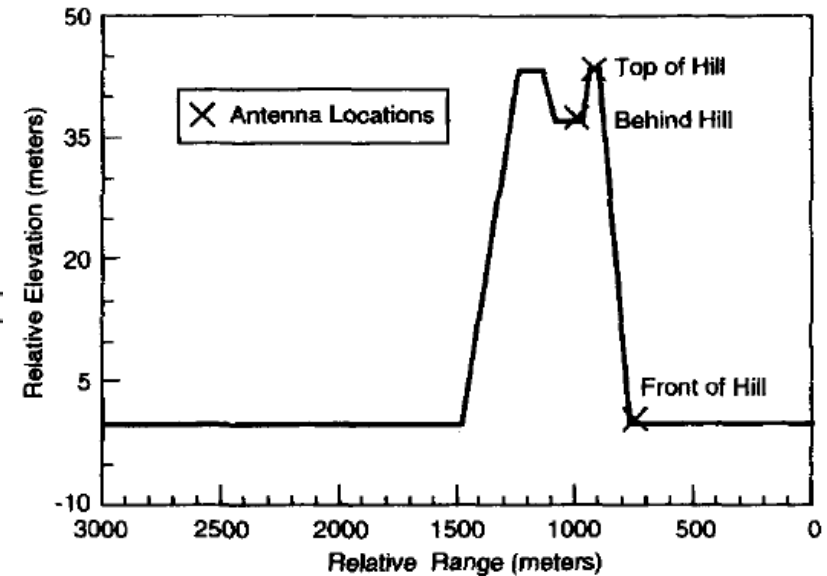
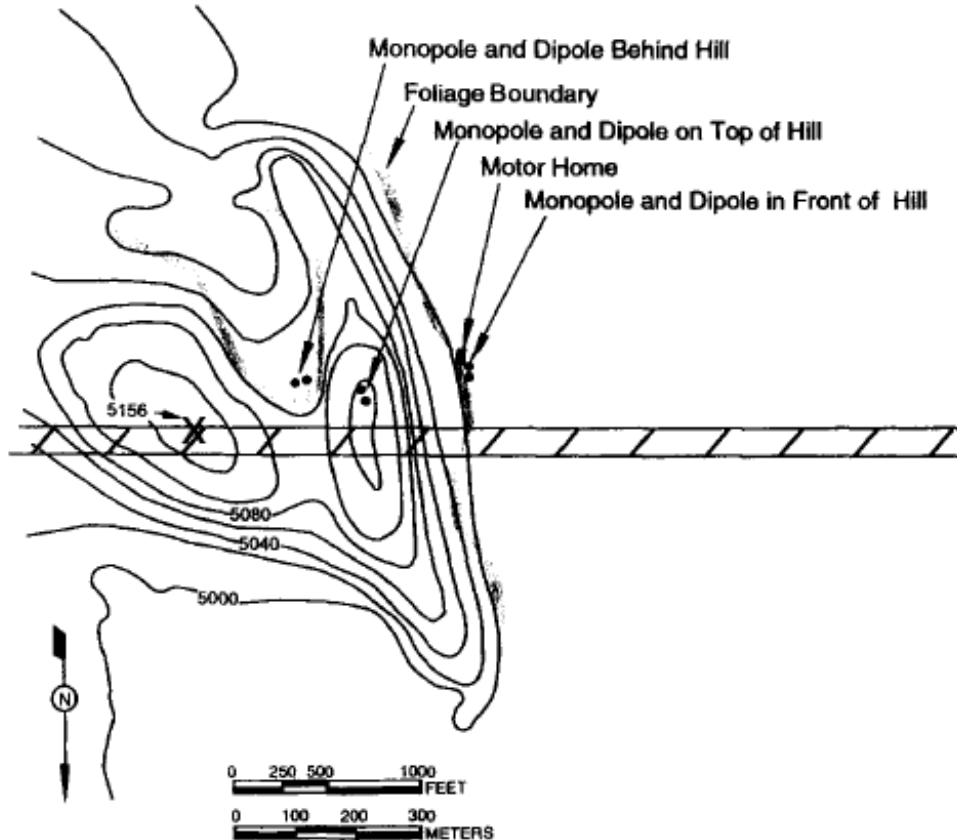
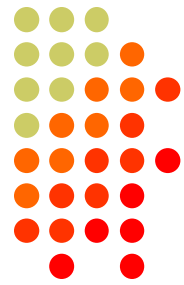
# Arnold Sommerfeld – Scattering and Diffraction from an Infinite Half-Plane and Wedge



# GTD-UTD



# Simple GTD Model of Cedar Valley Topography



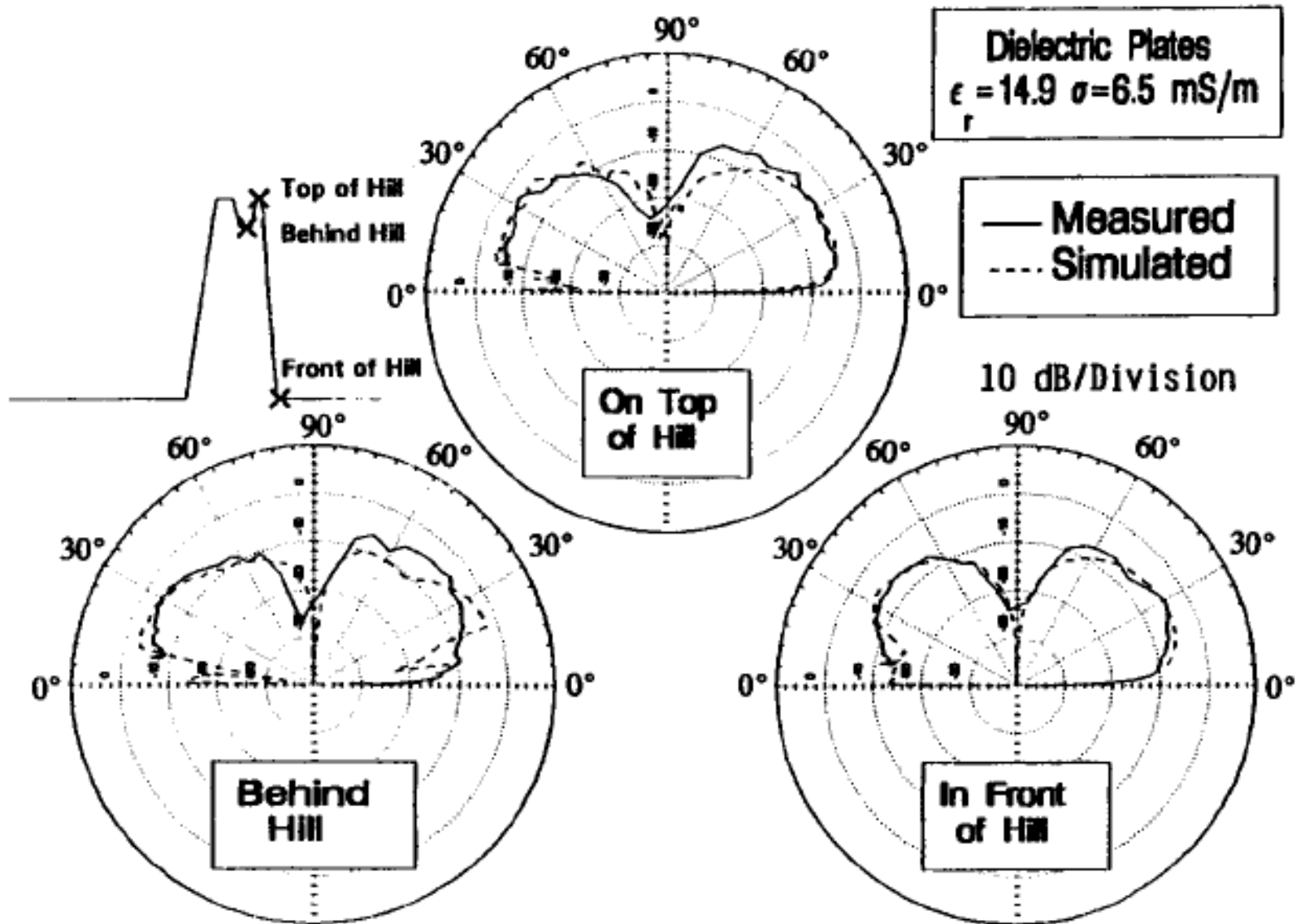
# Antennas in Front, On Top, and Behind Hill



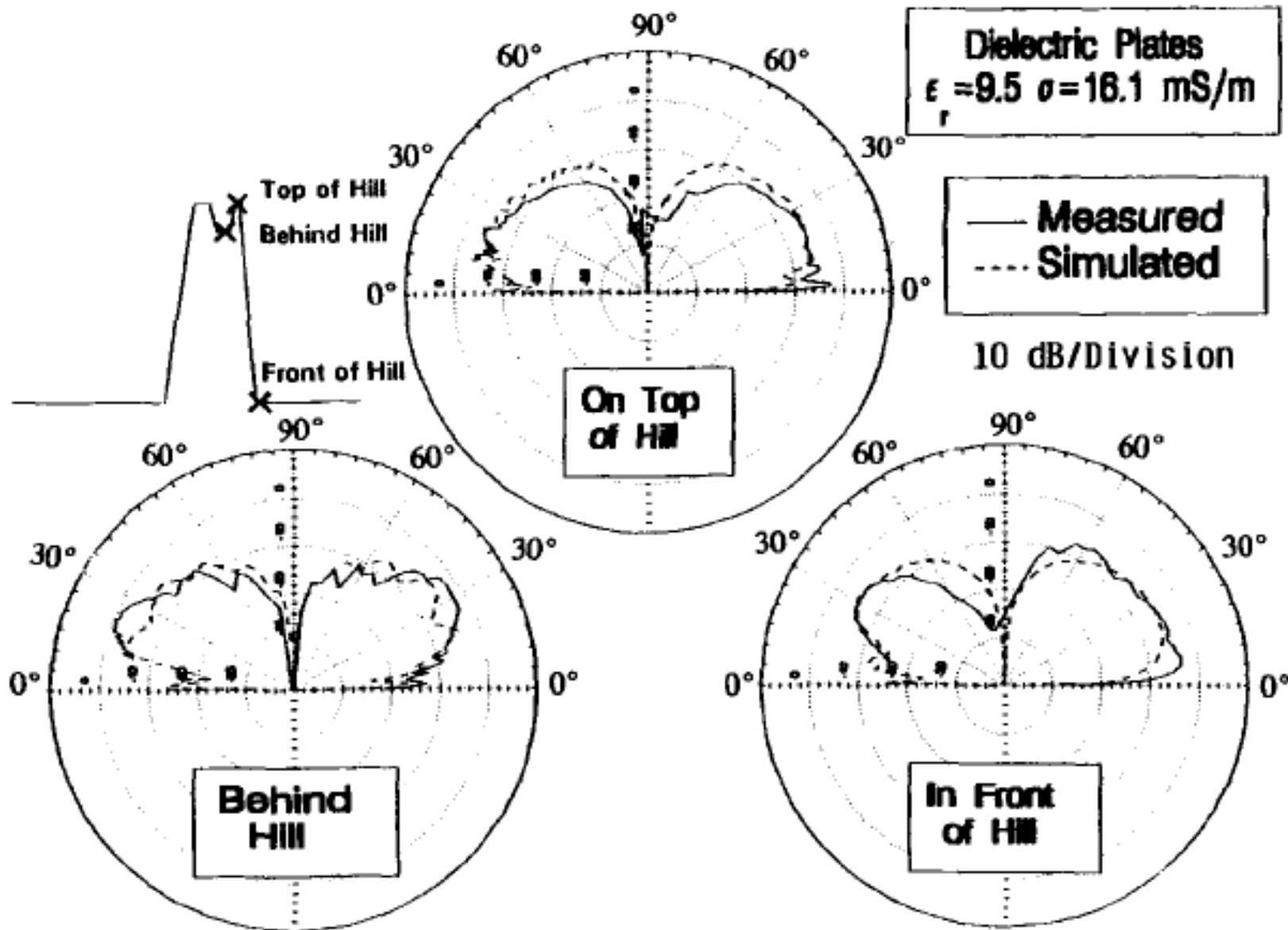
- Each monopole 4.9m with four 7.6m radials lying on the ground at each location
- Each dipole cut to be a  $\lambda/2$  at a height of 4.6m above locally flat ground at each location

Frequency (MHz)	Thickness (m)	Width (mm)
8.0150	4	60
15.3415	2	60
27.7415	1.1	60

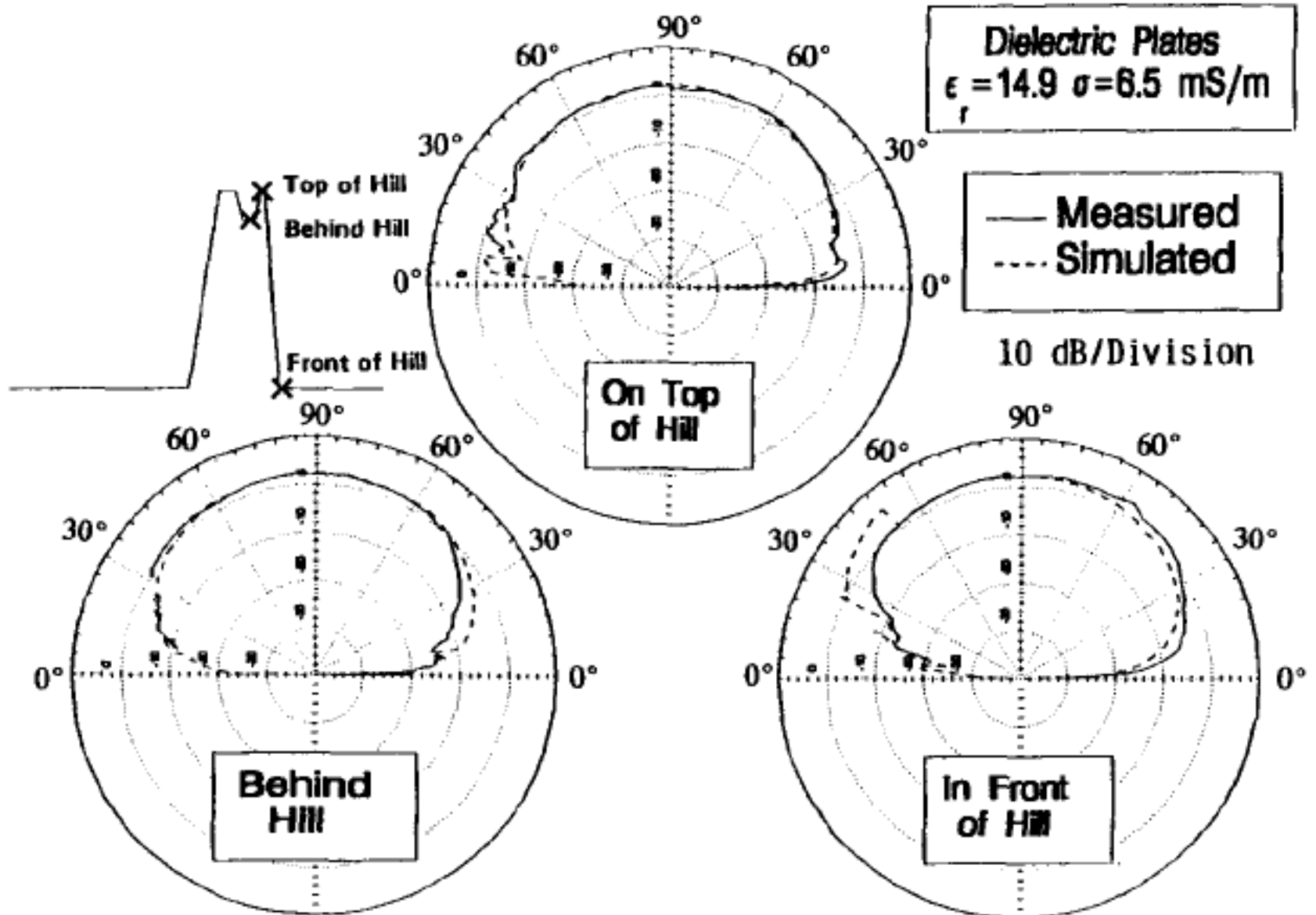
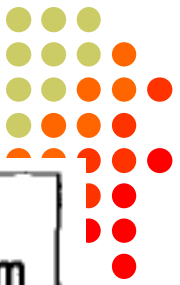
# 8 MHz Monopole Results



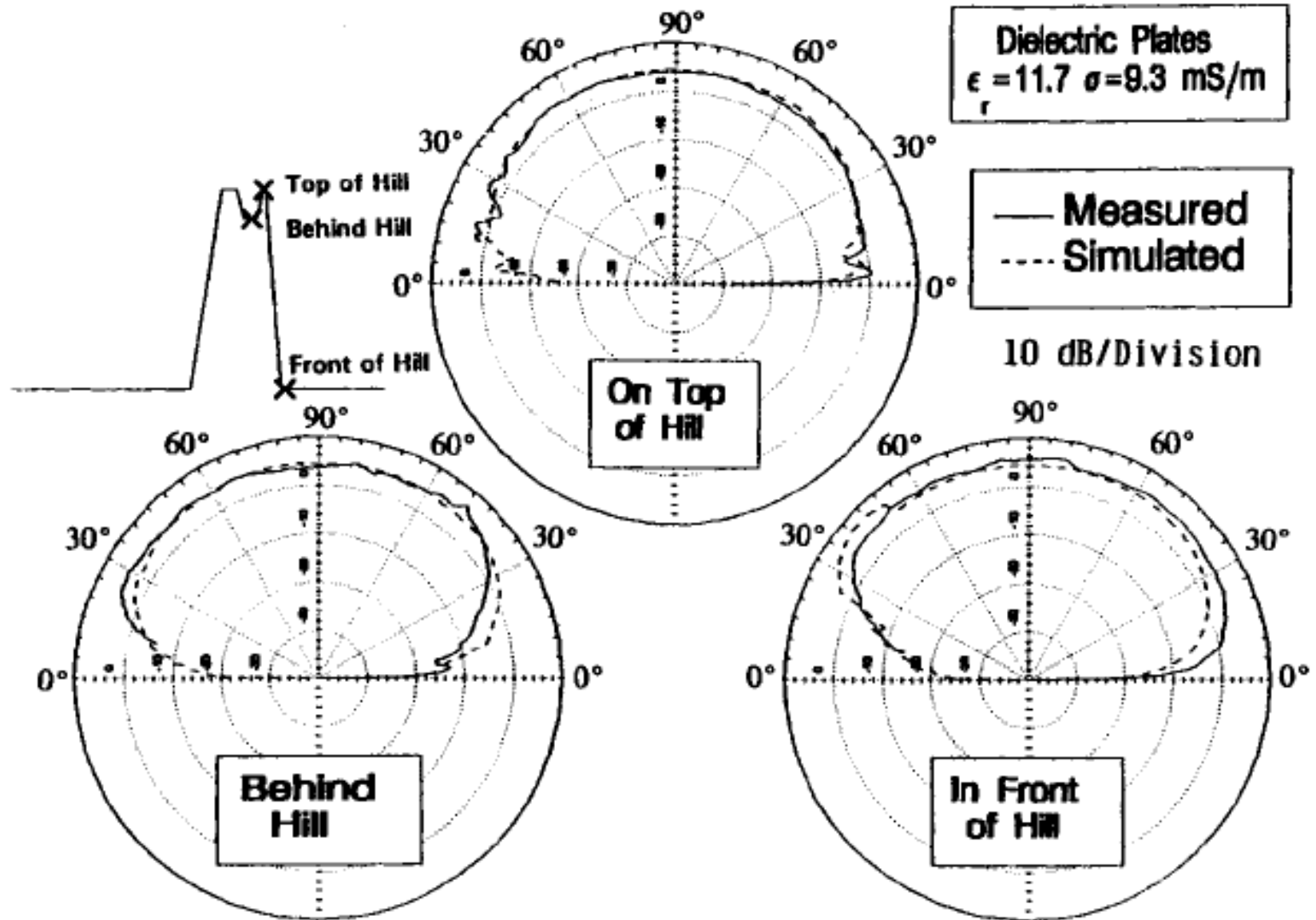
# 27 MHz Monopole Results



# 8 MHz Dipole Results

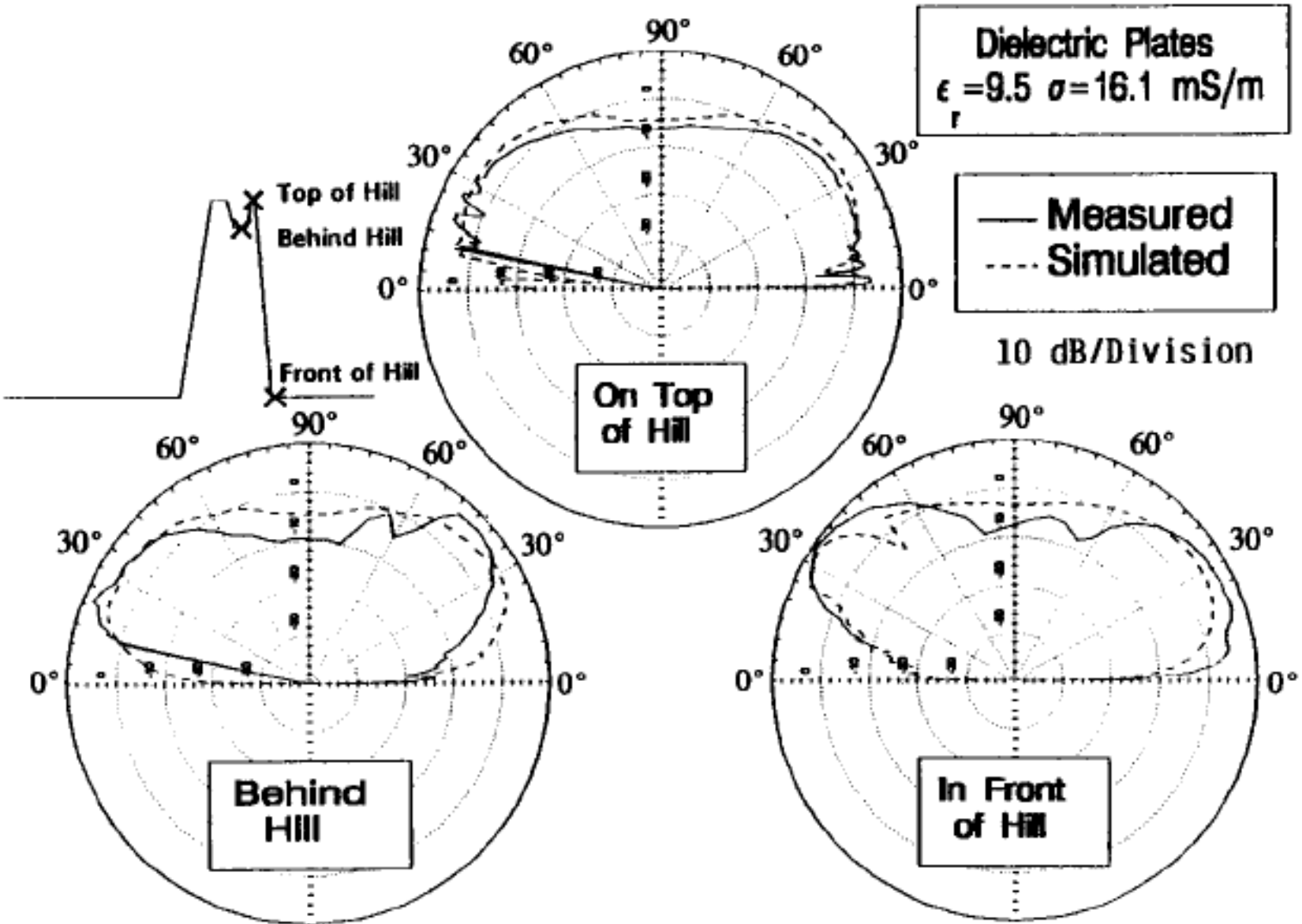
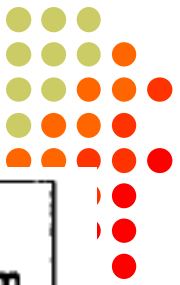


# 15 MHz Dipole Results





# 27 MHz Dipole Results



# Two Important Theses at Penn State for Irregular Terrain Modeling at HF



## **Title – M.S. Thesis**

**Simulation of irregular terrain effects on antenna patterns using the uniform geometrical theory of diffraction (UTD)**

### **Author**

Young, Joel S., 1964-

### **Pub date:**

1993.

## **Title – Ph. D. Thesis**

**Simulation of antenna patterns over 3-dimensional irregular terrain using the uniform geometrical theory of diffraction (UTD)**

**(Development of the paint system)**

### **Author**

Young, Joel S., 1964-

### **Pub date:**

1994.

# It Started Here at the ACES Conference and a Get-together at the Home on Top of W6NL's Mountain



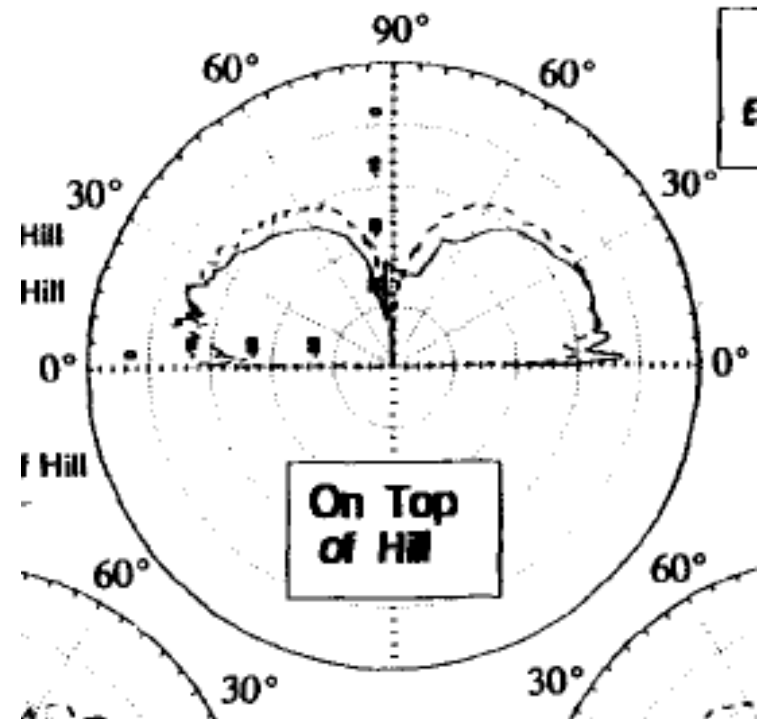
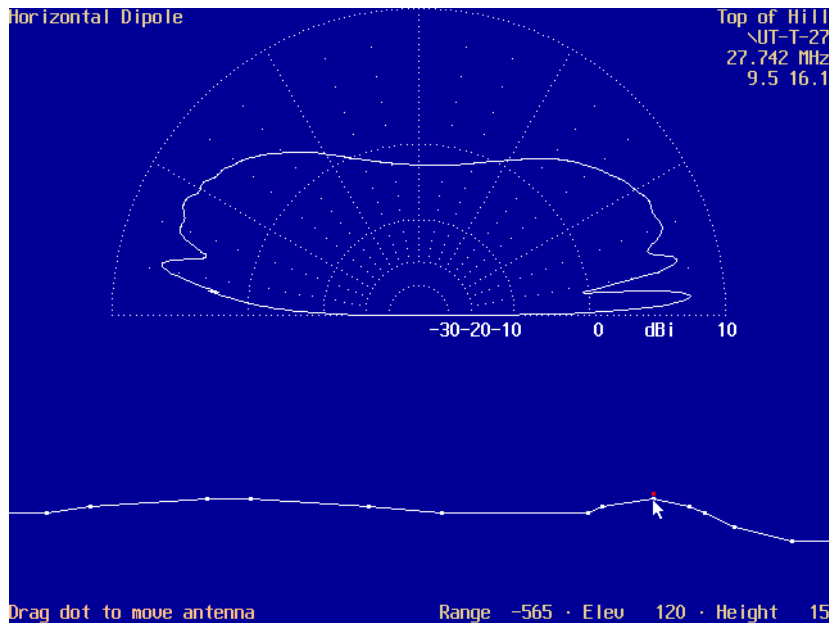
# Brian Beezley – K6STI Terrain Analyzer (TA)



Copyright 1998 by Brian Beezley, K6STI  
All Rights Reserved

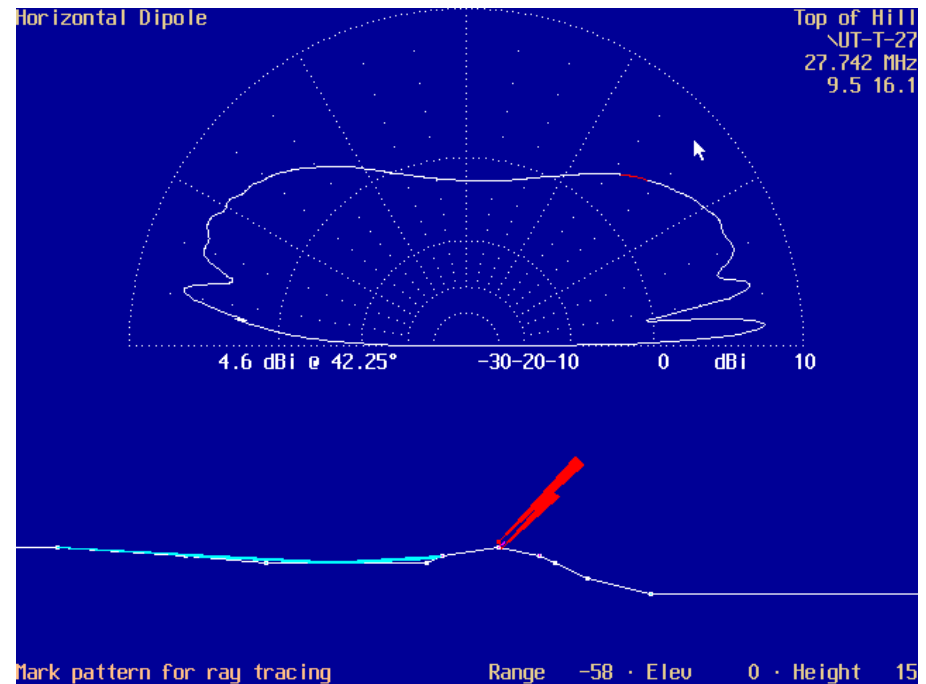
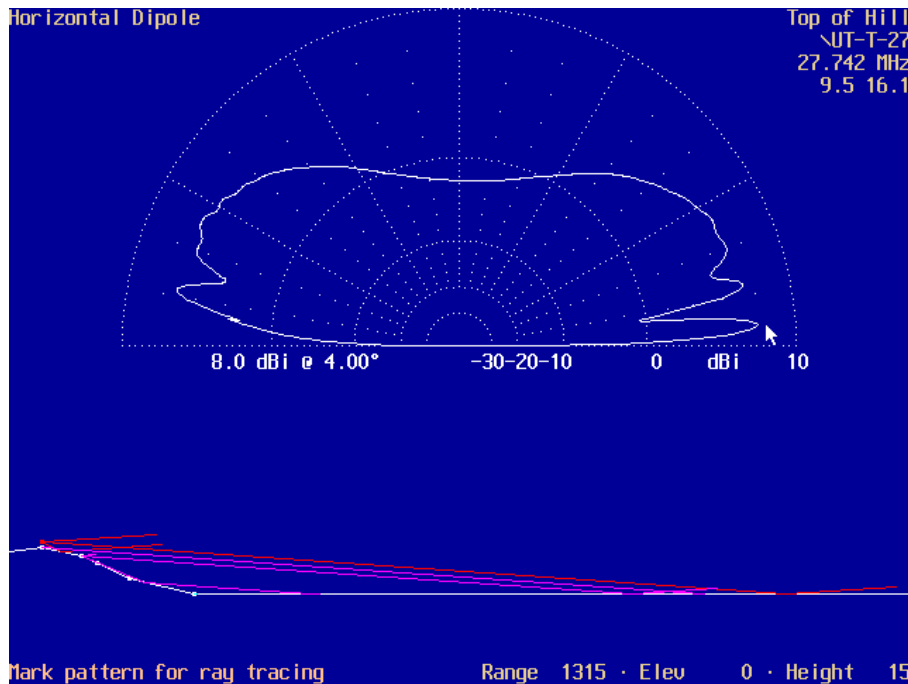
TA 1.0 Terrain Analyzer.....	1
Running TA.....	1
Plot Files.....	1
Terrain Files.....	2
Output Files.....	4
Slope Consolidation.....	4
Analysis Range.....	4
Diffraction Threshold.....	4
Ray Tracing.....	5
Sketches.....	5
Snapshot.....	5
Stacked Antennas.....	5
Undo/Redo.....	6
Automatic Stepping of Antenna Height.....	6
Notepad.....	7
Colors and Initialization.....	7
Validation, Artifacts, and Aliasing.....	7
Ensuring Accurate Models.....	8
Modeling Tips.....	10
SET Commands.....	11

# TA vs Simple GTD-UTD Model On Top of Hill 27 MHz

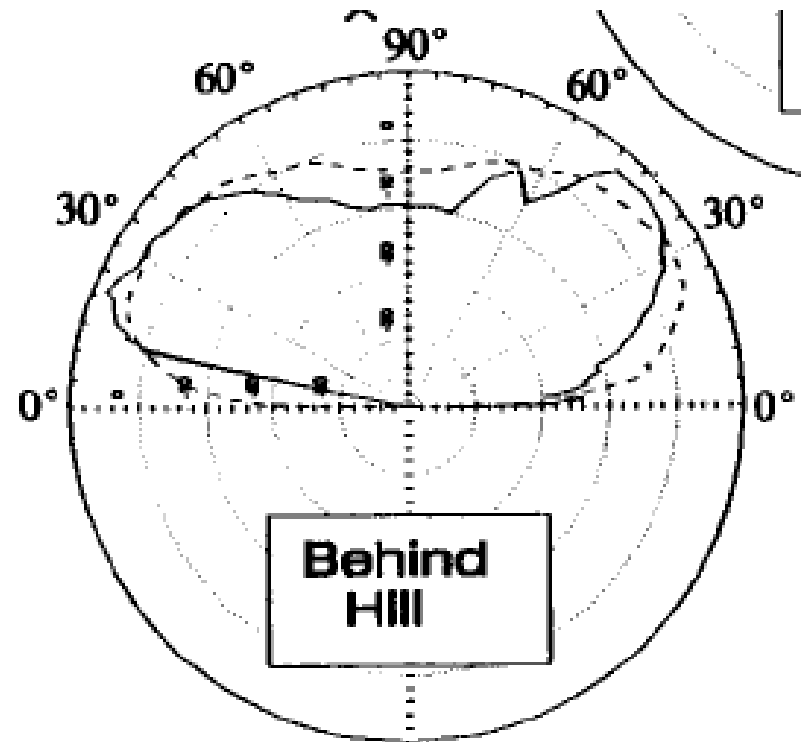
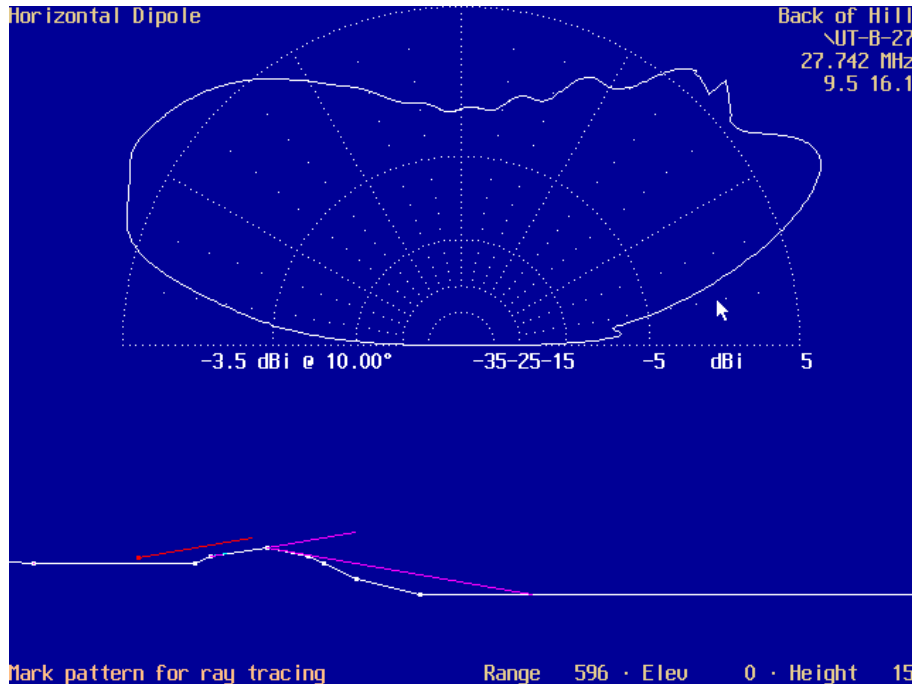


# TA Showing GO Reflected and GTD-UTD Diffracted Rays

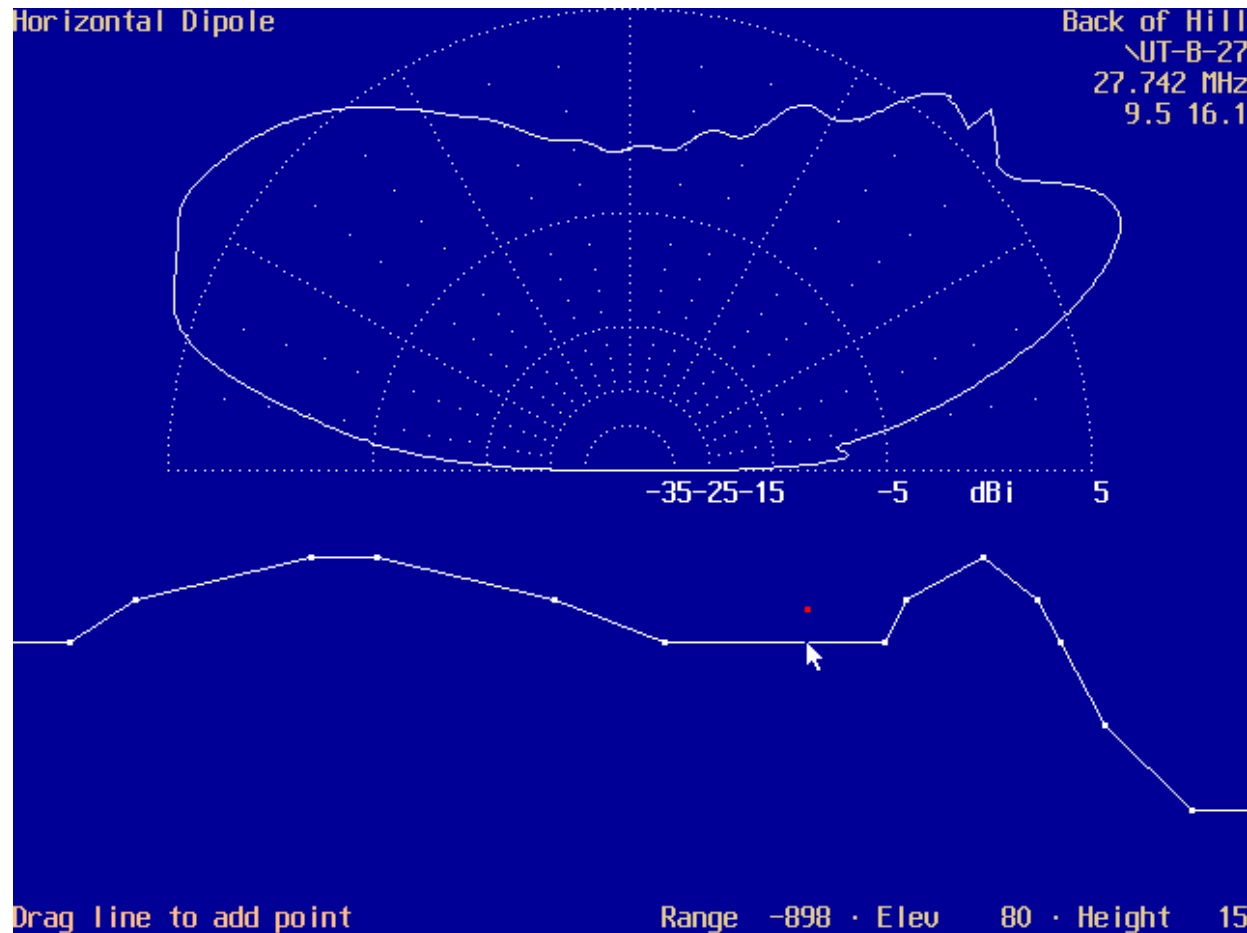
## Top of Hill 27 MHz



# TA vs Simple GTD-UTD Model Behind Hill 27 MHz

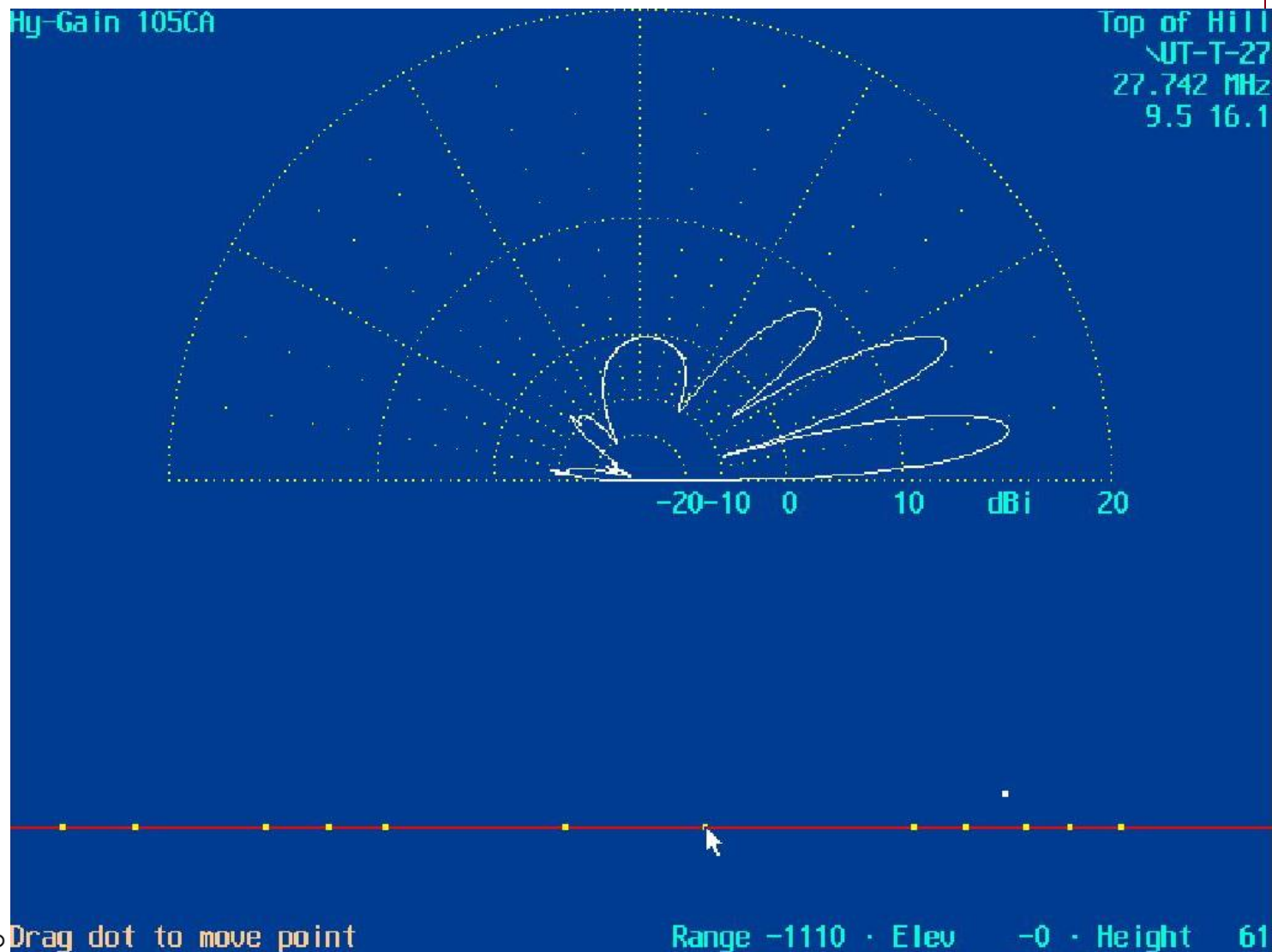


# TA vs Simple GTD-UTD Model Behind Hill 27 MHz Terrain Expanded

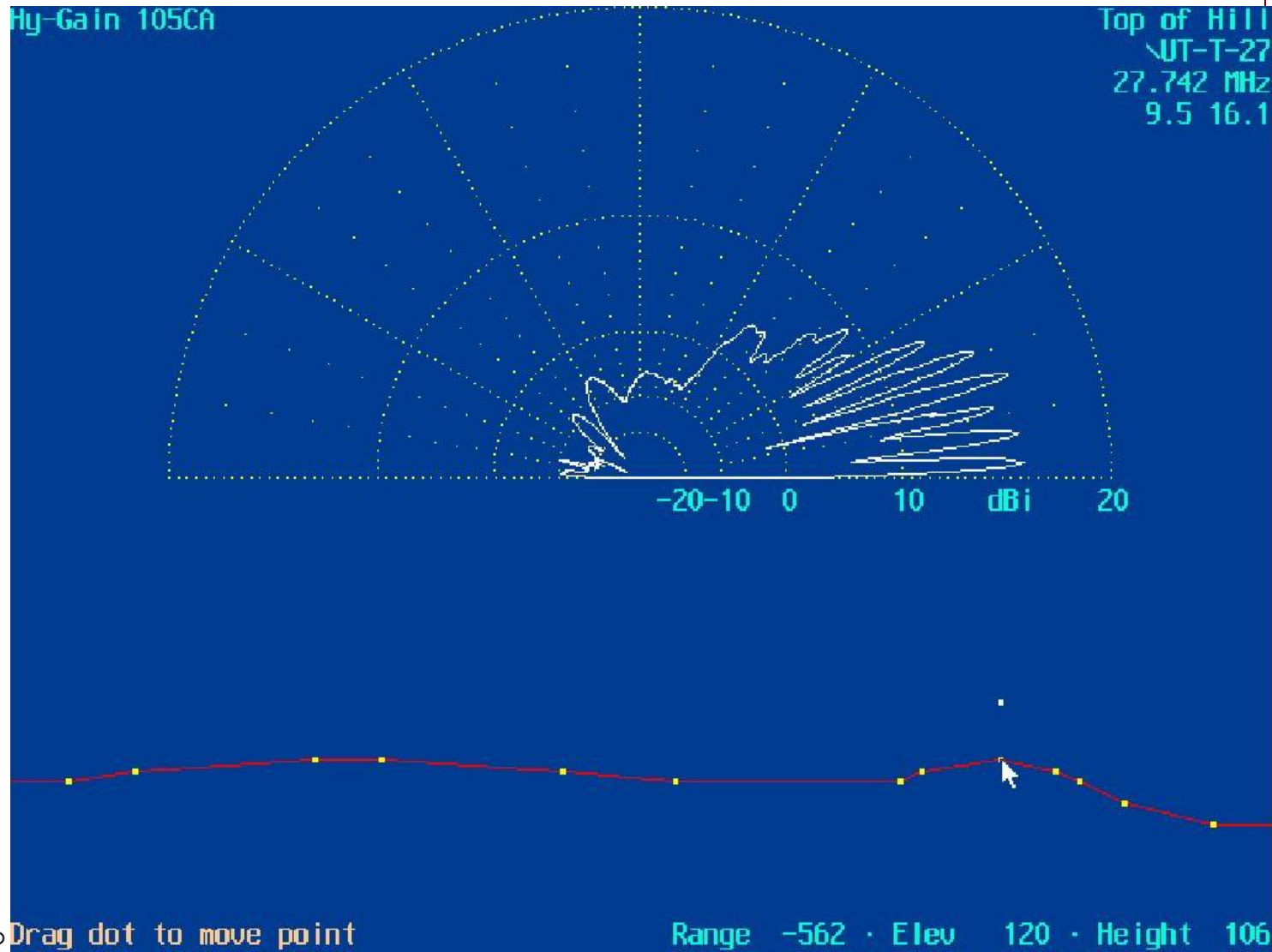




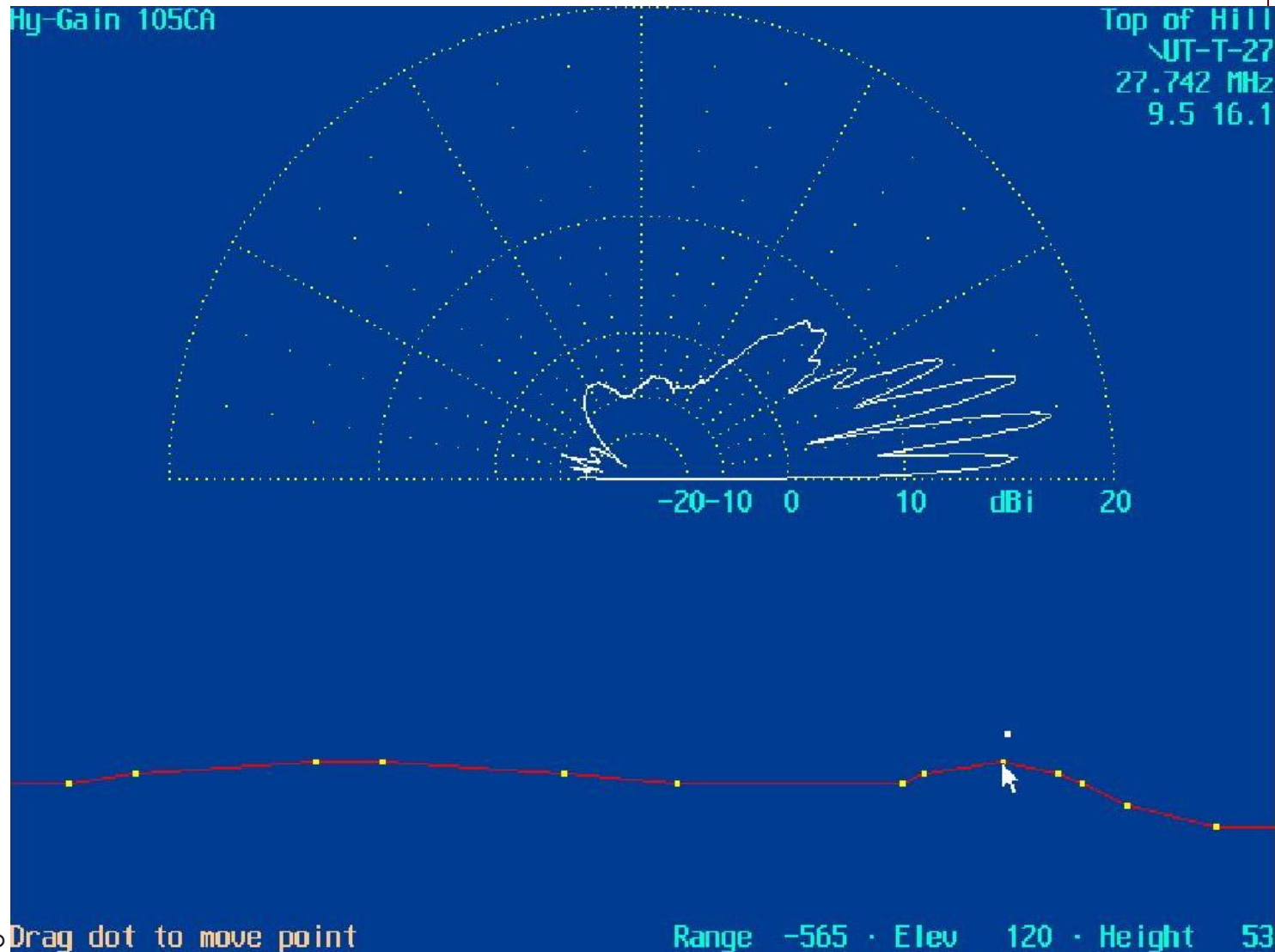
# K6STI TA - Hy-Gain 105CA 61 ft over Flat Ground



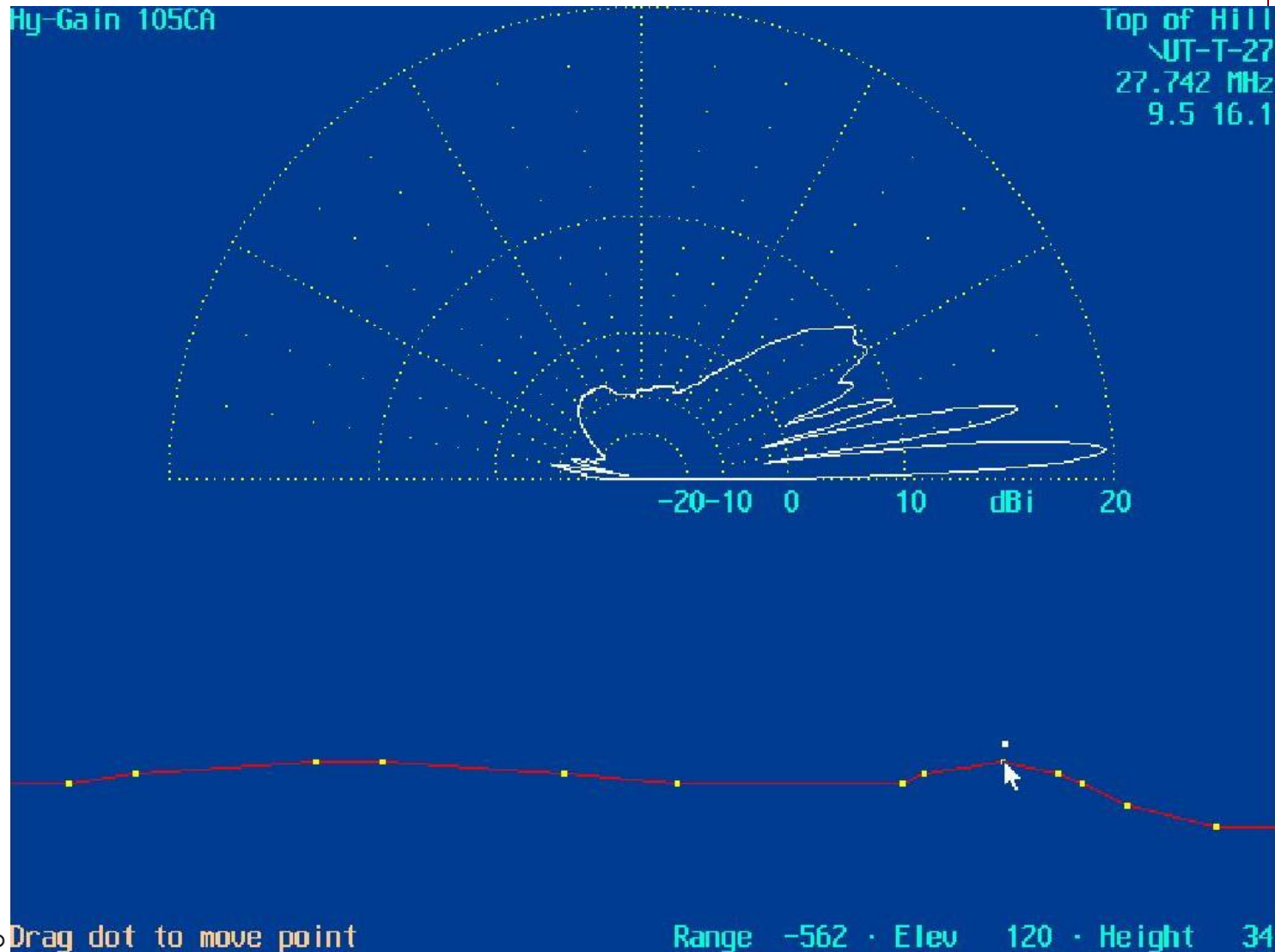
# Hy-Gain 105CA 106 ft on Top of Hill in Utah



# Hy-Gain 105CA 53 ft on Top of Hill in Utah



# Hy-Gain 105CA 34 ft on Top of Hill in Utah





# Dean Straw, N6BV, Created the High Frequency Terrain Assessment (HFTA) Program



“The subject of how to choose a QTH for working DX has fascinated Hams since the beginning of amateur operations. No doubt, Marconi spent a lot of time wandering around Newfoundland looking for a great radio QTH before making the first transatlantic transmission.”

The ARRL Antenna Book, 22st Ed.

Signal Hill  
St. John's, Newfoundland



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# N6BV and HFTA



- Dean completed a detailed study at ARRL HQ on the range of elevation angles needed for communication between various locations around the world.
- He computed statistics using IONCAP and later VOACAP for many receiver QTHs, solar conditions, seasons, time of day, frequency, etc.
- HFTA also computes the effect of irregular terrain on antenna patterns mainly with built in Yagi and Yagi stacks

# HFTA Elevation Angle Statistics and Patterns



HFTA (HF Terrain Assessment)

## HFTA, HF Terrain Assessment

Version 1.04, Copyright 2003-2004, ARRL, by N6BV, Mar. 02, 2004

**Frequency:** 14.2 MHz

**Diffraction:** ON

**Terrain Files:**

	Ant. Type	Heights	
1:	FLAT.PRO	Dipole	40 feet
2:	FLAT.PRO	6-Ele.	100 feet
3:			feet
4:			feet

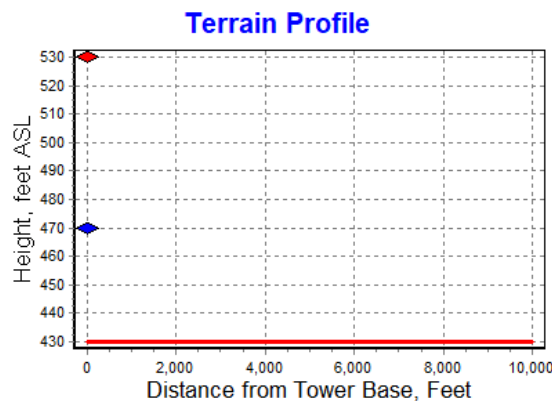
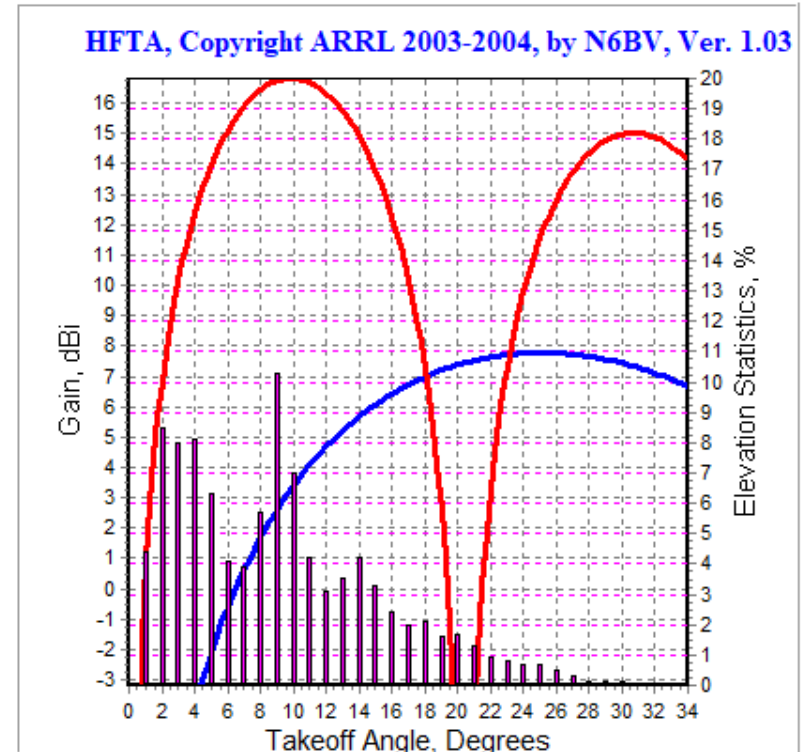
**Elevation File:** W3-DC-EU.PRN

**Max. Elev. Angle:** 34 deg.

**Options:**  Terrain 1,  Terrain 2,  Terrain 3,  Terrain 4,  Show Ants.

Buttons: **Options**, **Plot Terrain**, **Compute!**, **Exit**, **Help**

Output Graph, HFTA



# HFTA Elevation Angle Statistics and Patterns N6BV from CA to Japan



HFTA (HF Terrain Assessment)

## HFTA, HF Terrain Assessment

Version 1.04, Copyright 2003-2004, ARRL, by N6BV, Mar. 02, 2004

Frequency:  MHz

Diffraction: ON

Options

Terrain Files:	Ant. Type	Heights
1: FLAT.PRO	6-Ele.	100 feet
2: BVCAP330.PRO	6-Ele.	100 feet
3:		feet
4:		feet

Max. Elev. Angle

20 deg.

25 deg.

34 deg.

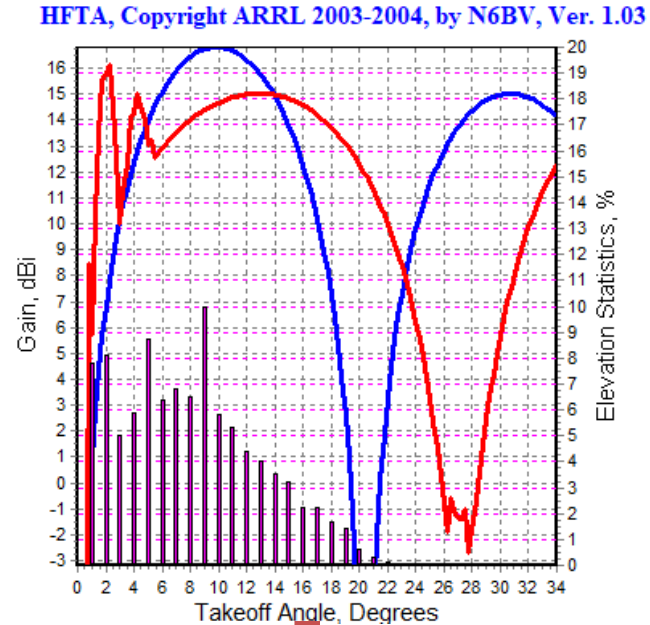
Compute! Exit

Plot Terrain

Show Ants.

Terrain Plot, HFTA

Output Graph, HFTA



Freq. = 14.2 MHz  
Max. Gain: 16.8 dBi

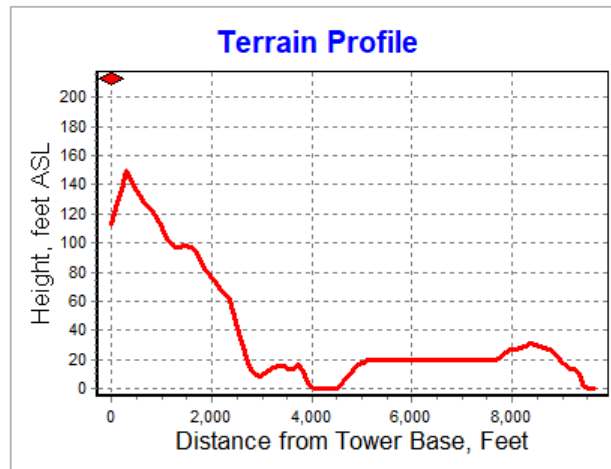
FLAT.PRO  
100 ft  
6-Ele.  
Fig. of Merit: 14.4

BVCAP330.PRO  
100 ft  
6-Ele.  
Fig. of Merit: 13.9

Elev. Statistic  
W6-LA-JA.PRN

Print Out File

Close



Print

Close



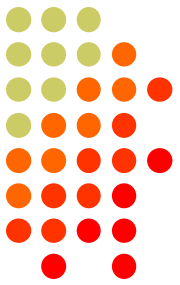
# How to get Terrain Files

## Stu Phillips – K6TU



- <https://paas.k6tu.net> (New site)
- Register and it is free to get terrain files
- Best to purchase \$35 subscription for more features and easy transfer
- You will get terrain files for every 1 degree for all azimuths around the latitude and longitude that you put in
- Can get lat and long from Google Maps

# Comparison of WP3R/WA3FET Contest Station on Highest Hill on the North Central Coast of Puerto Rico to the WP3R New Home Station (Flat Ground) to USA and to Europe



- **WP3R Contest Station –**
- **160 – Dipole 60ft**
- **80 – Dipole 60ft**
- **40 – 3 el Wire Yagi (Wide space like 4 el) 60 ft**
- **20 – 6 el 60ft**
- **15 – 6 el 60ft**
- **10 – 6 el 30ft**
  
- **WP3R new House Station –**
- **160 – Inverted-L modeled as dipole 60ft**
- **80 – dipole 60ft**
- **40 – dipole 60ft**
- **20 – 3 el Yagi 60ft Skyhawk**
- **15 – 3 el Yagi 60ft Skyhawk**
- **10 – 4 el Yagi 60ft Skyhawk**

# Contest Station Built in 1998 at the WA3FET Puerto Rico Farm using the WP3R Callsign





## WA3FET/KP4 Winning Contest Location from Puerto Rico using Callsign WP3R

- Won ARRL SS Phone High Power Single Op 10 years in row – Still have Phone Record – KE3Q
- Won ARRL SS CW High Power Single Op 8/10 years in row – KE3Q
- Won ARRL DX World Both Modes High Power Single Op one year – K9PG
- Won ARRL DX World Both Modes Low Power Single Op the next year – K9PG

# WA3FET-WP3R Contest Station, Arecibo PR



# WA3FET-WP3R Contest Station, Arecibo PR





# WA3FET-WP3R Contest Station, Arecibo PR



WP3R/WA3FET Contest Site  
Arecibo, Puerto Rico  
(view from access road)







# WP3R/WA3FET Contest Site

6el each 15-20m OWA 48 ft boom (interlaced)

80-160m Inverted V  
Common feed-point

6el 10m OWA 24 ft boom

60 ft Rohn 55 Tower

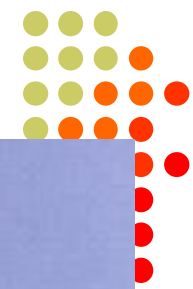


WP3R/WA3FET Contest Site  
Arecibo, Puerto Rico

6el each 15-20m  
OWA 48 ft boom

6el 10m OWA  
24 ft boom





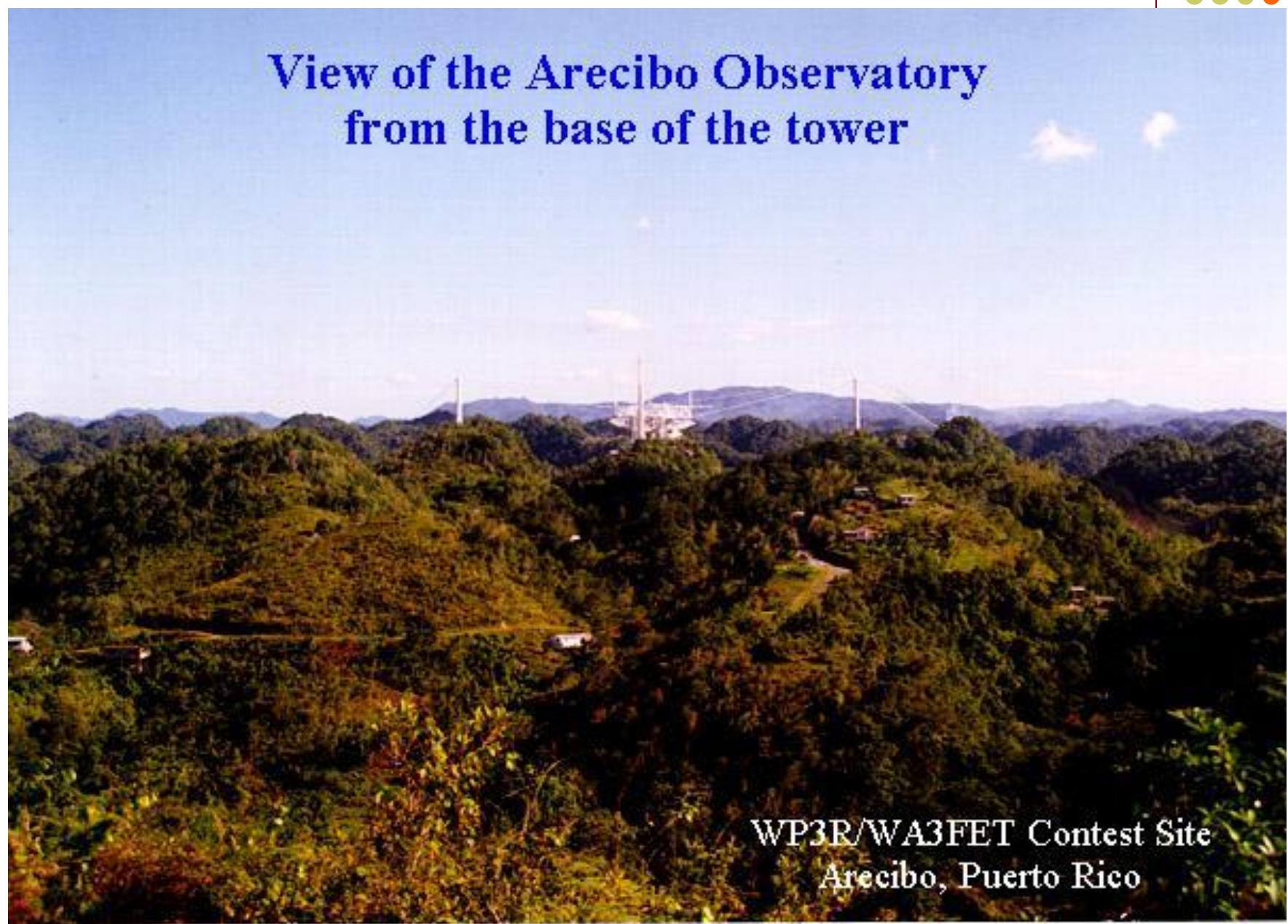
3el 40m Yagi supported by 500 ft catenary  
(boom length= 52 ft)

<== driven element

WP3R/WA3FET Contest Site  
Arecibo, Puerto Rico



# View of the Arecibo Observatory from the base of the tower



WP3R/WA3FET Contest Site  
Arecibo, Puerto Rico



# Following to USA (330 deg bearing) 160m

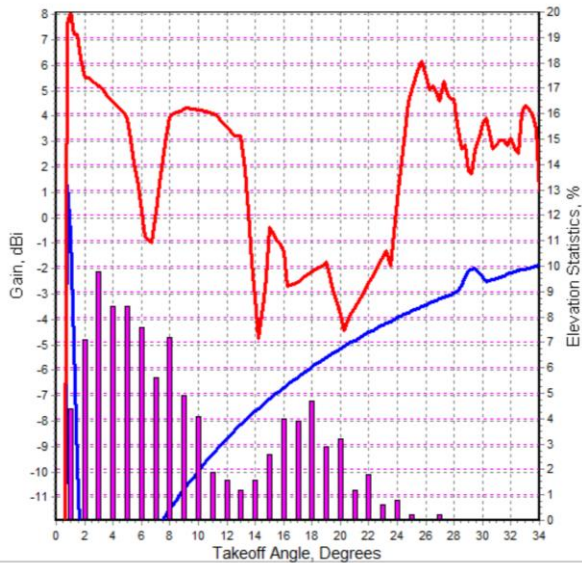
## Red – WP3R/WA3FET Contest Station

## Blue – WP3R New Home Station



Output Graph, HFTA

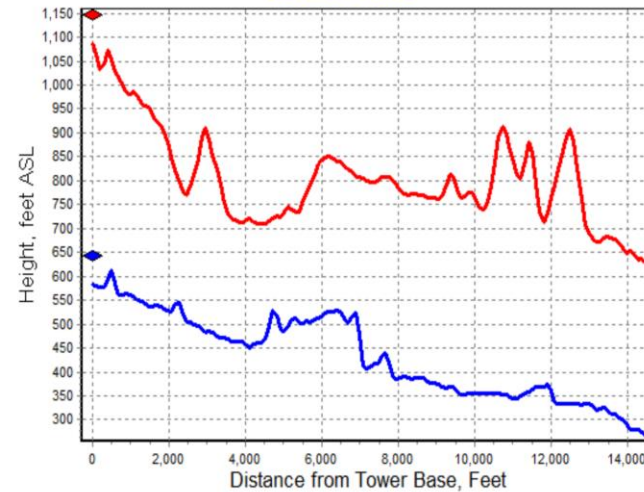
HFTA, Copyright ARRL 2003-2004, by N6BV, Ver. 1.03



**Freq. = 1.8 MHz**  
 Max. Gain: 8.1 dBi  
 WP3R-HOUSE-330.0  
 60 ft  
 Dipole  
 Fig. of Merit: -8.4  
 WP3R-MTN-330.00.1  
 60 ft  
 Dipole  
 Fig. of Merit: 3.4

**Elev. Statistic**  
 KP2-US.PRN

Terrain Profile



WP3R-HOUSE-330.0  
 60 ft  
 WP3R-MTN-330.00.  
 60 ft

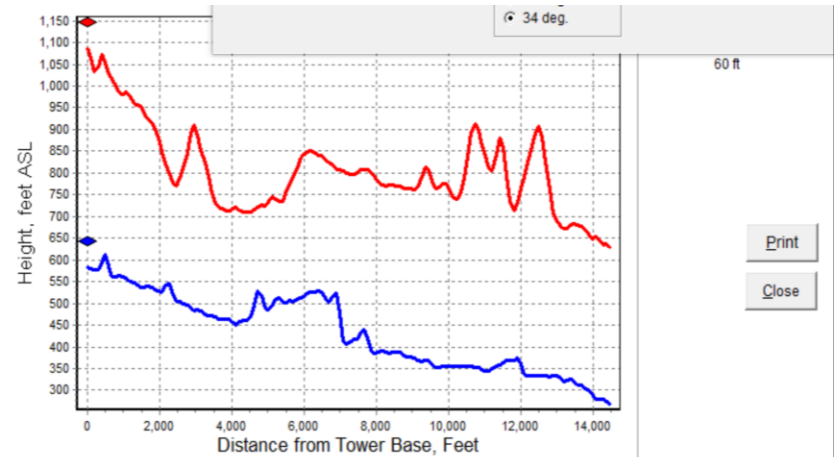
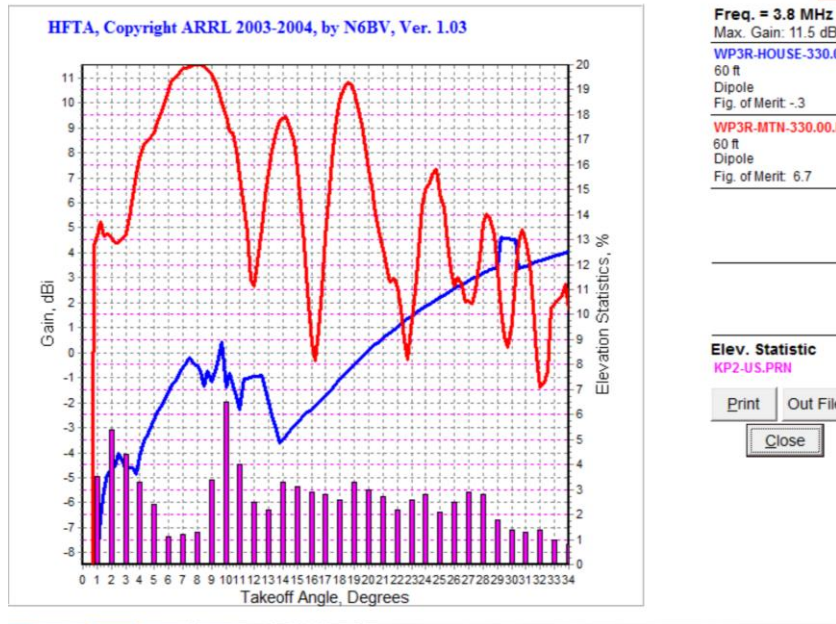
# Following to USA (330 deg bearing) 80m

## Red – WP3R/WA3FET Contest Station

## Blue – WP3R New Home Station



Output Graph, HFTA



# Following to USA (330 deg bearing) 40m

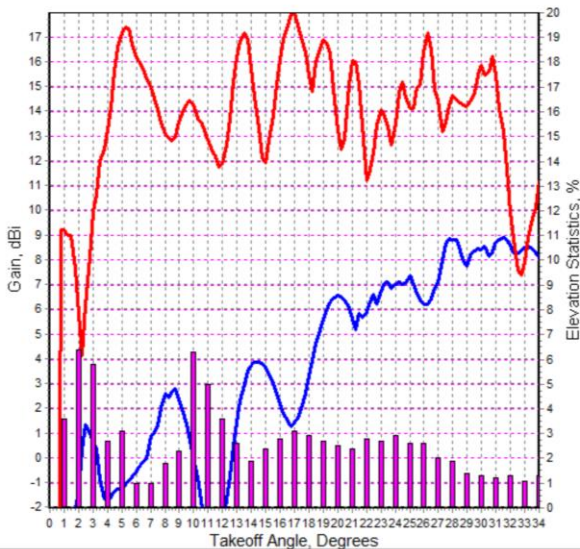
## Red – WP3R/WA3FET Contest Station

## Blue – WP3R New Home Station



Output Graph, HFTA

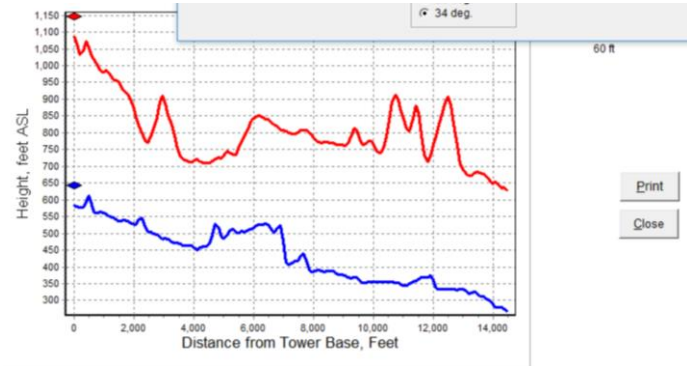
HFTA, Copyright ARRL 2003-2004, by N6BV, Ver. 1.03



**Freq. = 7.0 MHz**  
Max. Gain: 18.0 dE  
WP3R-HOUSE-330.0  
60 ft  
Dipole  
Fig. of Merit: 3.8  
WP3R-MTN-330.00J  
60 ft  
4-El.  
Fig. of Merit: 13.7

**Elev. Statistic**  
KP2-US.PRN

Print Out File  
Close



Document1 - Word 3:31 PM 3/13/2017

# Following to USA (330 deg bearing) 20m

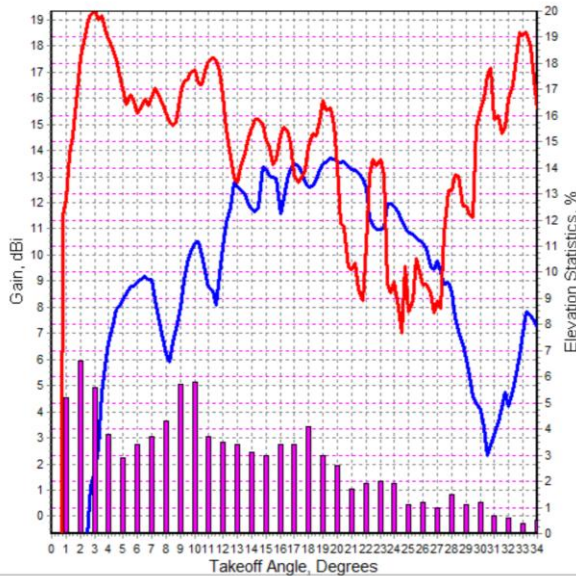
## Red – WP3R/WA3FET Contest Station

## Blue – WP3R New Home Station



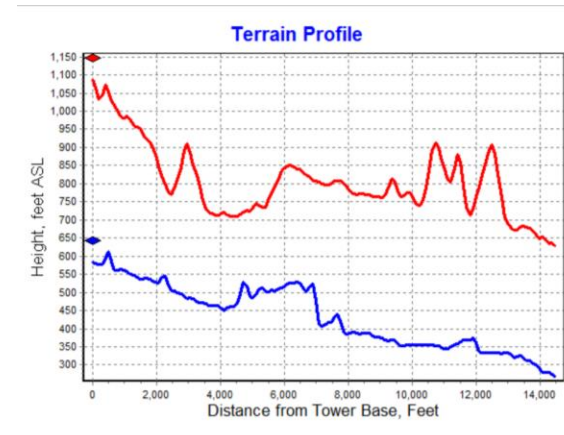
tput Graph, HFTA

HFTA, Copyright ARRL 2003-2004, by N6BV, Ver. 1.03



**Freq. = 14.0 MHz**  
 Max. Gain: 19.3 dBi  
**WP3R-HOUSE-330.0**  
 60 ft  
 3-Ele.  
 Fig. of Merit: 9.9  
**WP3R-MTN-330.00.F**  
 60 ft  
 6-Ele.  
 Fig. of Merit: 15.6

**Elev. Statistic**  
 KP2-US.PRN



**WP3R-HOUSE-330.0**  
 60 ft  
**WP3R-MTN-330.00.F**  
 60 ft



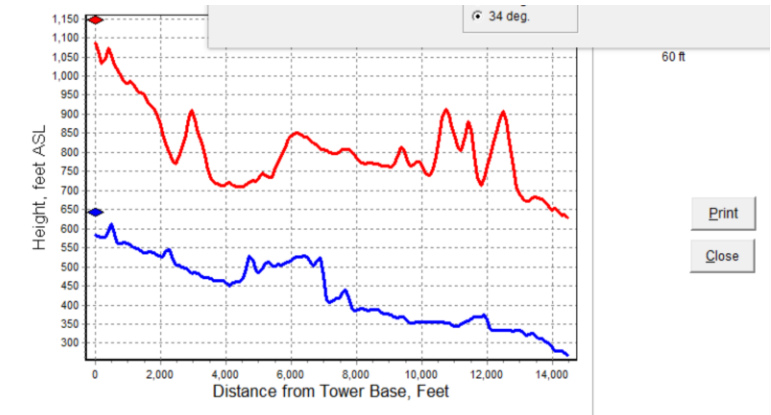
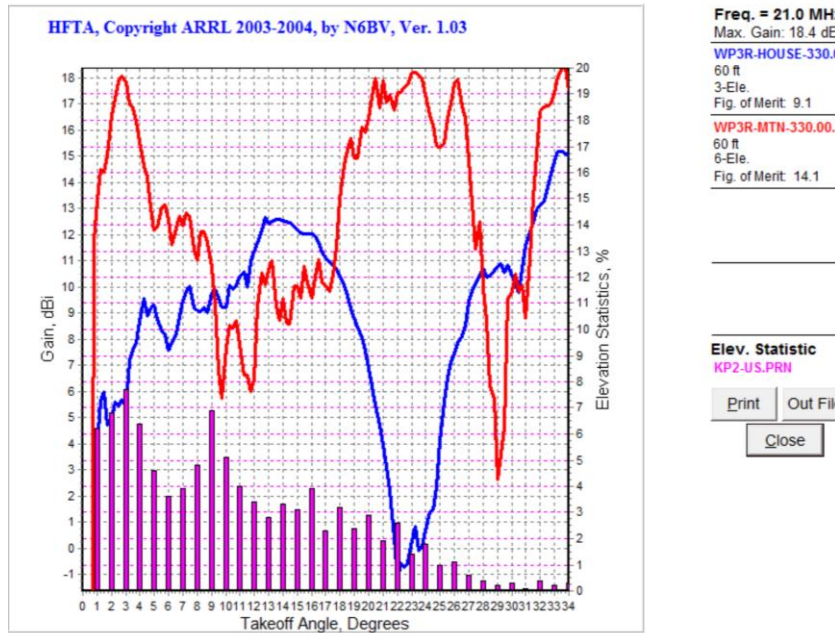
# Following to USA (330 deg bearing) 15m

## Red – WP3R/WA3FET Contest Station

## Blue – WP3R New Home Station



Output Graph, HFTA



# Following to USA (330 deg bearing) 10m

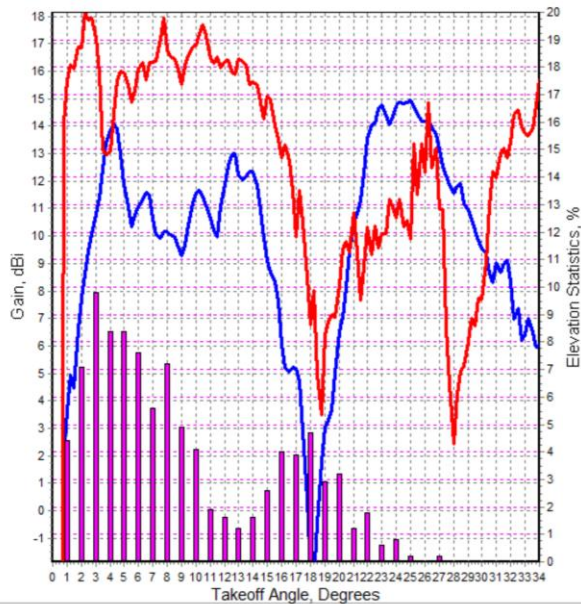
## Red – WP3R/WA3FET Contest Station

## Blue – WP3R New Home Station



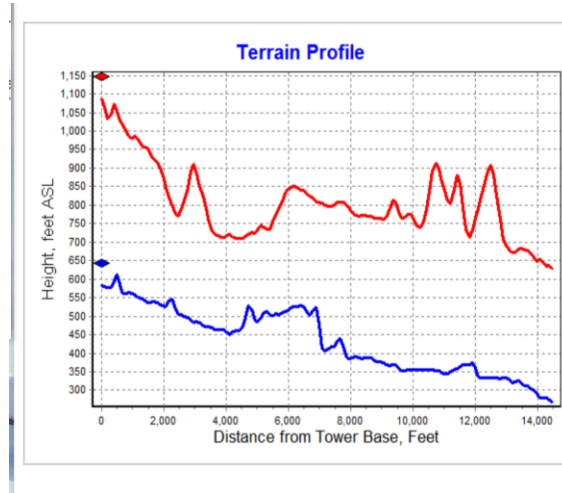
tput Graph, HFTA

HFTA, Copyright ARRL 2003-2004, by N6BV, Ver. 1.03



**Freq. = 28.0 MHz**  
**Max. Gain: 18.1 dB**  
**WP3R-HOUSE-330.0**  
 60 ft  
 4-Ele.  
 Fig. of Merit: 10.5  
**WP3R-MTN-330.00.1**  
 30 ft  
 6-Ele.  
 Fig. of Merit: 15.3

**Elev. Statistic**  
 KP2-US.PRN



**WP3R-HOUSE-330.0**  
 60 ft  
**WP3R-MTN-330.00.1**  
 60 ft

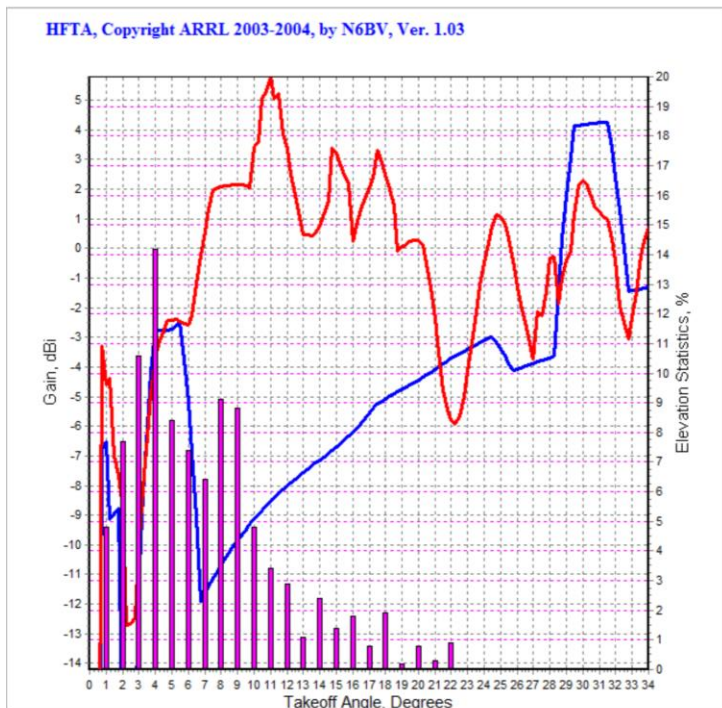
# Following to Europe (45 deg bearing) 160m

## Red – WP3R/WA3FET Contest Station

## Blue – WP3R New Home Station



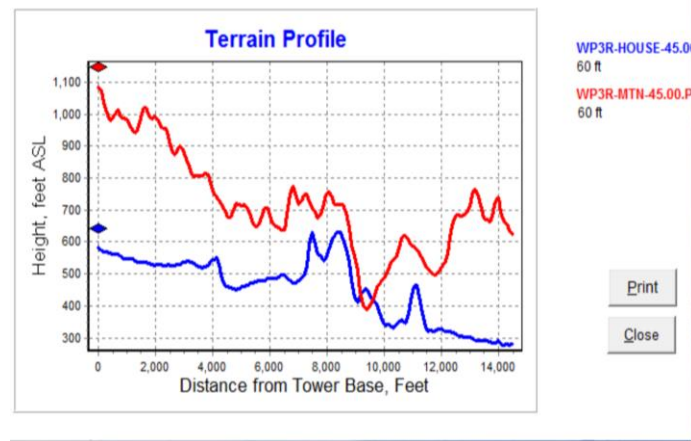
Output Graph, HFTA



Freq. = 1.8 MHz  
Max. Gain: 5.8 dBi  
WP3R-HOUSE-45.0I  
60 ft  
Dipole  
Fig. of Merit: -6.4  
WP3R-MTN-45.00.P  
60 ft  
Dipole  
Fig. of Merit: 0

Elev. Statistic  
KP2-EU.PRN  
Print Out File  
Close

Terrain Plot, HFTA



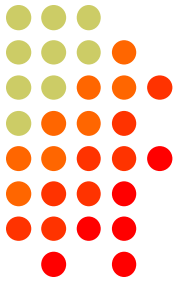
WP3R-HOUSE-45.0I  
60 ft  
WP3R-MTN-45.00.P  
60 ft

Print  
Close

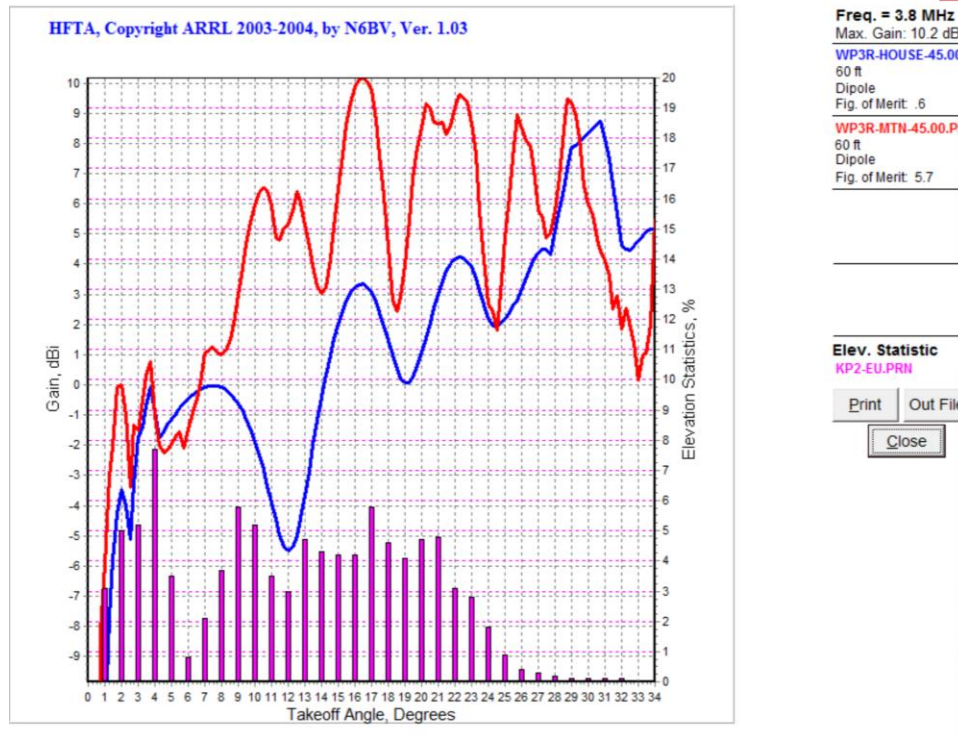
# Following to Europe (45 deg bearing) 80m

## Red – WP3R/WA3FET Contest Station

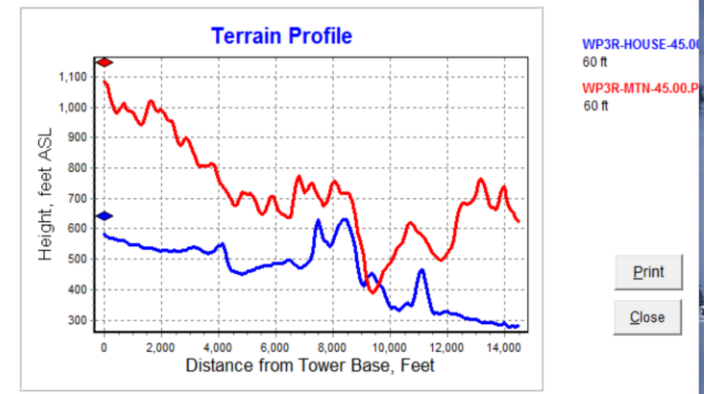
## Blue – WP3R New Home Station



Output Graph, HFTA



Terrain Plot, HFTA

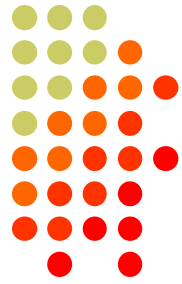




# Following to Europe (45 deg bearing) 40m

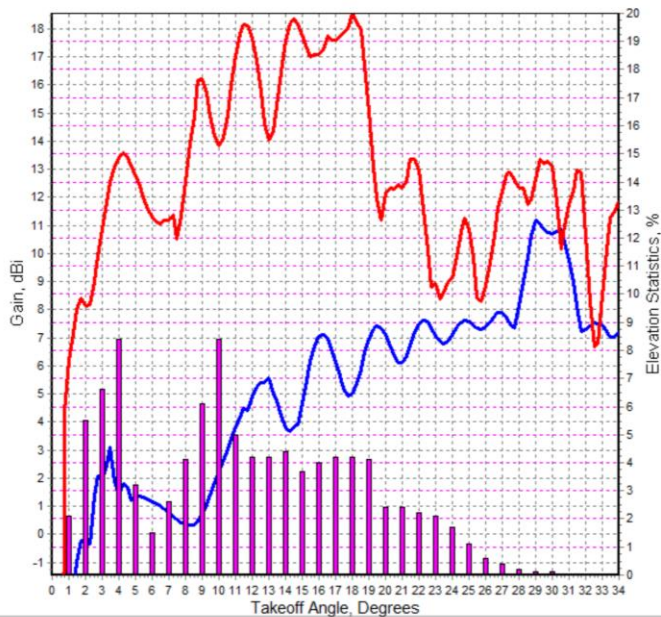
## Red – WP3R/WA3FET Contest Station

## Blue – WP3R New Home Station



Output Graph, HFTA

HFTA, Copyright ARRL 2003-2004, by N6BV, Ver. 1.03

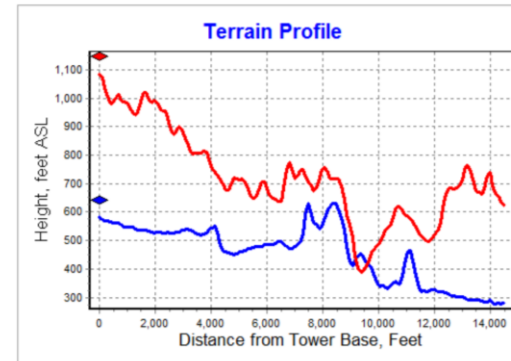


Freq. = 7.0 MHz  
Max. Gain: 18.6 dB  
WP3R-HOUSE-45.00  
60 ft  
Dipole  
Fig. of Merit: 4.2  
WP3R-MTN-45.00.P  
60 ft  
4-El.  
Fig. of Merit: 14.9

Elev. Statistic  
KP2-EU.PRN

Print Out File

Close



WP3R-HOUSE-45.00  
60 ft  
WP3R-MTN-45.00.P  
60 ft

Print

Close

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# Following to Europe (45 deg bearing) 20m

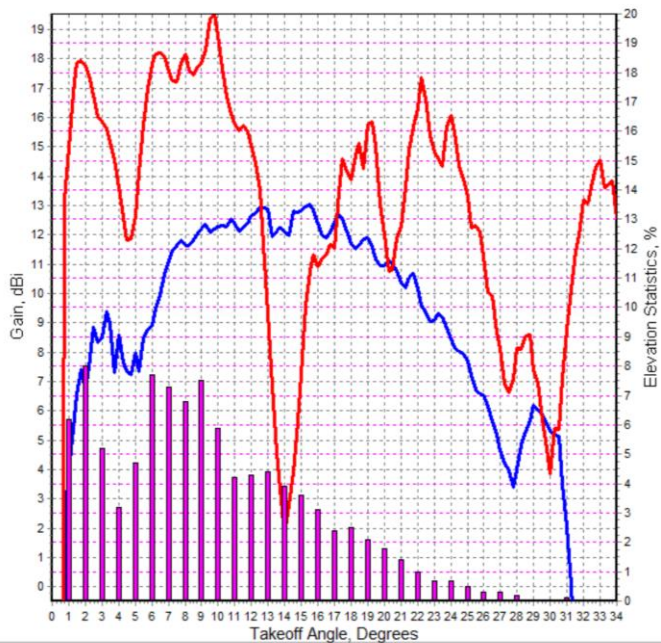
## Red – WP3R/WA3FET Contest Station

## Blue – WP3R New Home Station



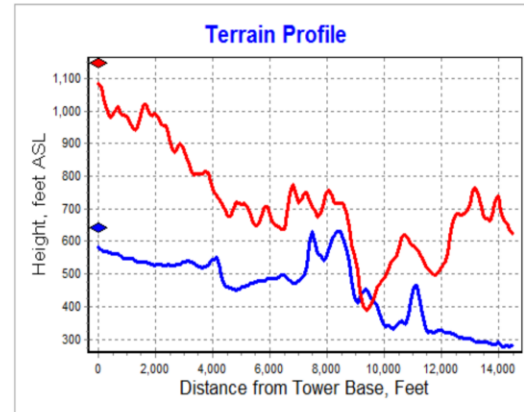
Output Graph, HFTA

HFTA, Copyright ARRL 2003-2004, by N6BV, Ver. 1.03



Freq. = 14.0 MHz  
 Max. Gain: 19.5 dBi  
 WP3R-HOUSE-45.00  
 60 ft  
 3-Ele.  
 Fig. of Merit: 10.9  
 WP3R-MTN-45.00.PP  
 60 ft  
 6-Ele.  
 Fig. of Merit: 16

Elev. Statistic  
 KP2-EU.PRN  
 Print Out File  
 Close



WP3R-HOUSE-45.00  
 60 ft  
 WP3R-MTN-45.00.PP  
 60 ft

Print  
 Close

# Following to Europe (45 deg bearing) 15m

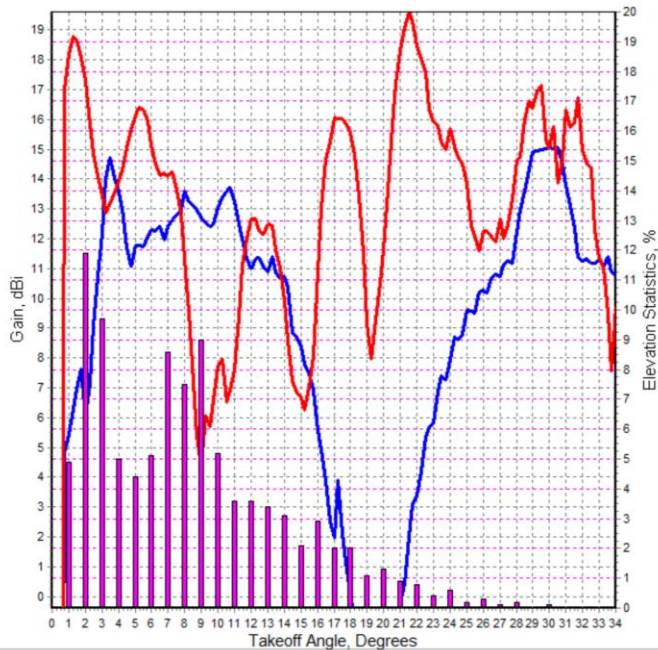
## Red – WP3R/WA3FET Contest Station

## Blue – WP3R New Home Station



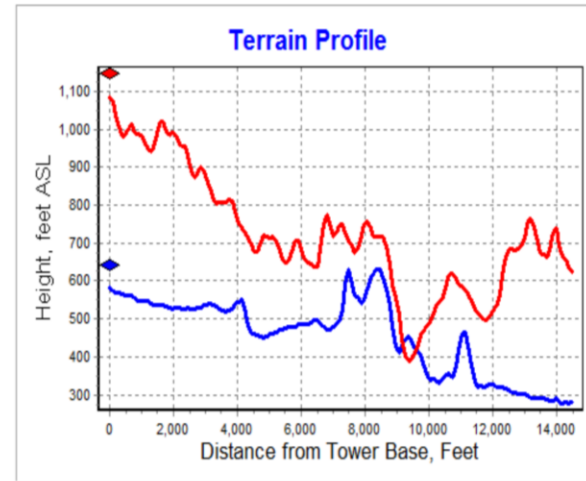
tput Graph, HFTA

HFTA, Copyright ARRL 2003-2004, by N6BV, Ver. 1.03



Freq. = 21.0 MHz  
 Max. Gain: 19.6 dBi  
 WP3R-HOUSE-45.0  
 60 ft  
 3-Ele.  
 Fig. of Merit: 11.3  
 WP3R-MTN-45.00.P  
 60 ft  
 6-Ele.  
 Fig. of Merit: 14.2

Elev. Statistic  
 KP2-EU.PRN



WP3R-HOUSE-45.0  
 60 ft  
 WP3R-MTN-45.00.F  
 60 ft



# Following to Europe (45 deg bearing) 10m

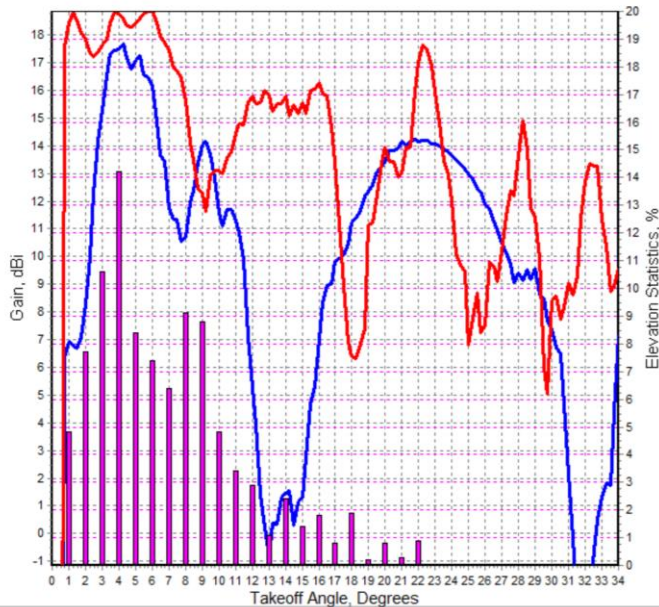
## Red – WP3R/WA3FET Contest Station

## Blue – WP3R New Home Station



tput Graph, HFTA

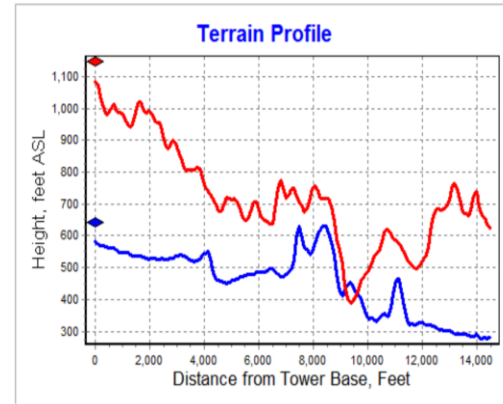
HFTA, Copyright ARRL 2003-2004, by N6BV, Ver. 1.03



**Freq. = 28.0 MH**  
 Max. Gain: 18.9 dB  
 WP3R-HOUSE-45.0  
 60 ft  
 4-Ele.  
 Fig. of Merit: 14.2  
 WP3R-MTN-45.00.F  
 30 ft  
 6-Ele.  
 Fig. of Merit: 17.1

**Elev. Statistic**  
 KP2-EU.PRN  
 Print Out Fil  
 Close

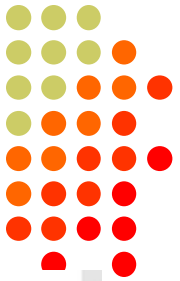
Terrain Plot, HFTA



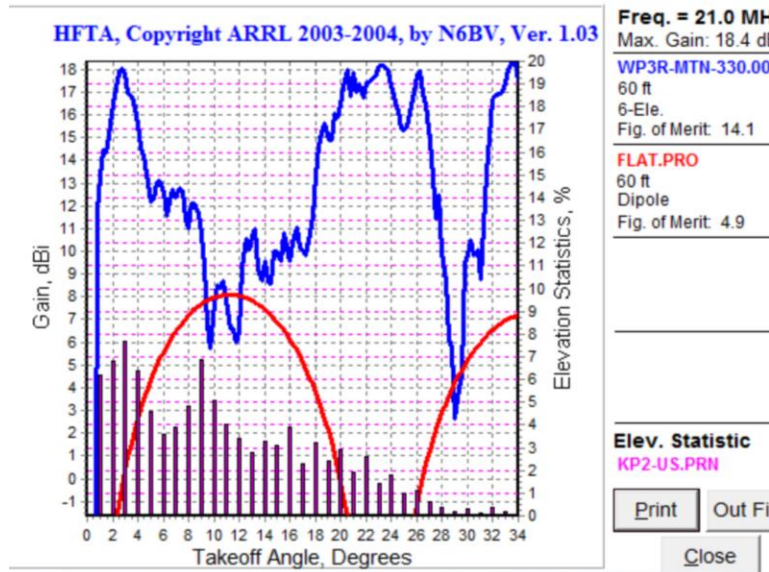
WP3R-HOUSE-45.00  
 60 ft  
 WP3R-MTN-45.00.F  
 60 ft

Print  
 Close

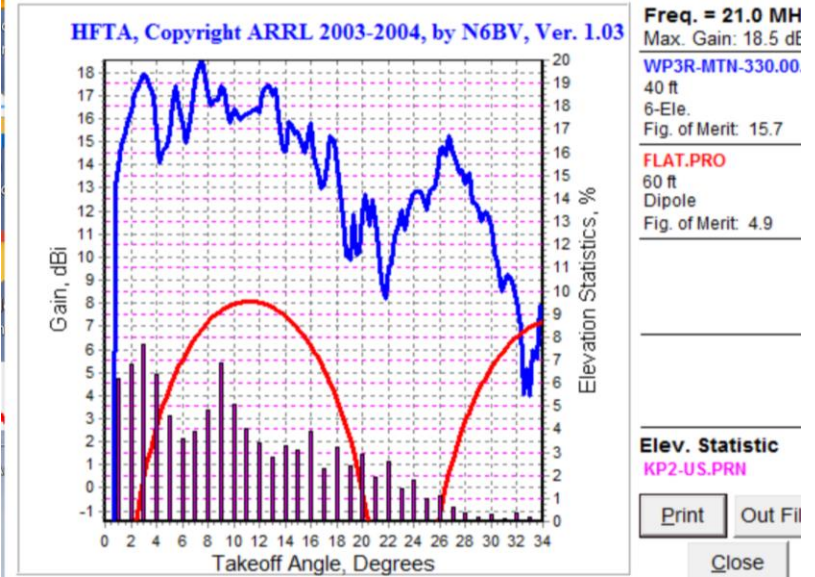
# Following to USA (330 deg bearing) 15m WP3R/WA3FET Contest Station 60 ft vs 40 ft



Output Graph, HFTA



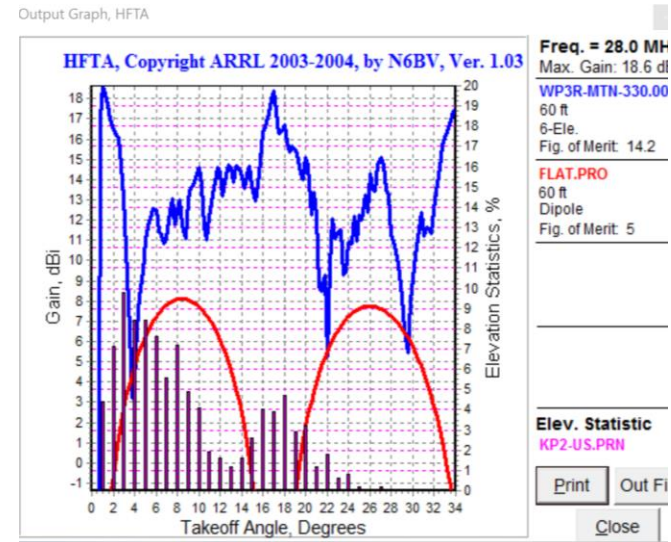
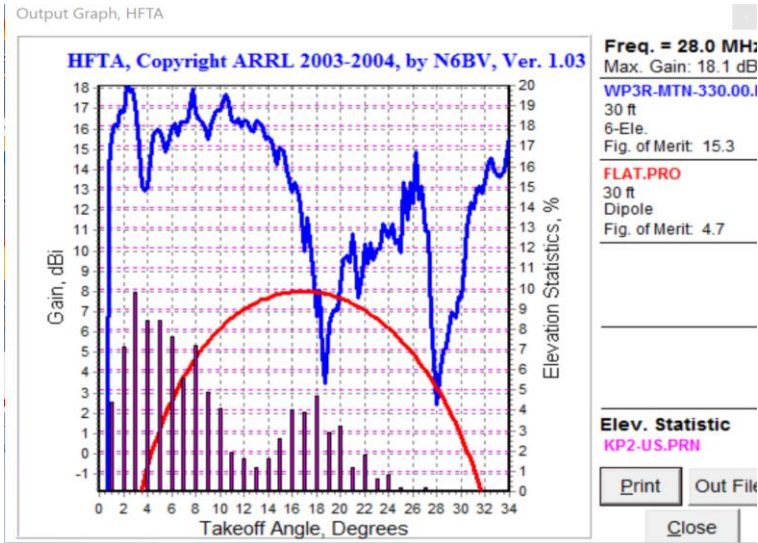
Output Graph, HFTA



On 15m, the height of 60ft is too high

On 15m, a height of 40 ft would be better

# Following to USA (330 deg bearing) 10m WP3R/WA3FET Contest Station 30 ft vs 60 ft



On 10m, 30 ft was a good choice for height

On 10m, a height of 60 ft would have been too high

We certainly guessed correctly for the signals to USA except  
for some reduced angle coverage on 15m

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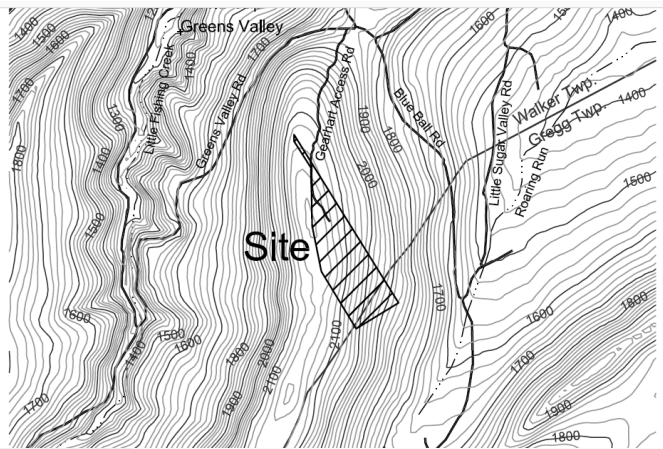
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# Camp Kilowatt (Camp K) Contest Station on The Magic Mountain – KC3R (N3EB, WA3FET, K0LO, NK8Q, K3ARL, K3GEM)



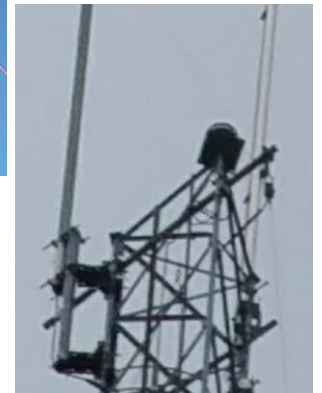
- HFTA Shows Incredible Terrain Enhancement
- Rime and Ice and Wind and Lightning – All Big Issues
- The 20m 6 Element OWA-ICE Design on 52 ft Boom
- 44 MPH with 1.5 inch radial ice
- SWR < 2 (13.25 – 14.95 MHz); SWR < 1.5 (13.75 – 14.9 MHz)



# 20m 6 Element OWA-ICE Design on 52 ft Boom Stack at 44 ft, 84 ft, and 124 ft All Turned by K0XG Ring Rotators



- **K0XG Rings are Super Strong and Towers and Anchors at Camp K are too !!!**





# Camp K – More Photos



PHOTO

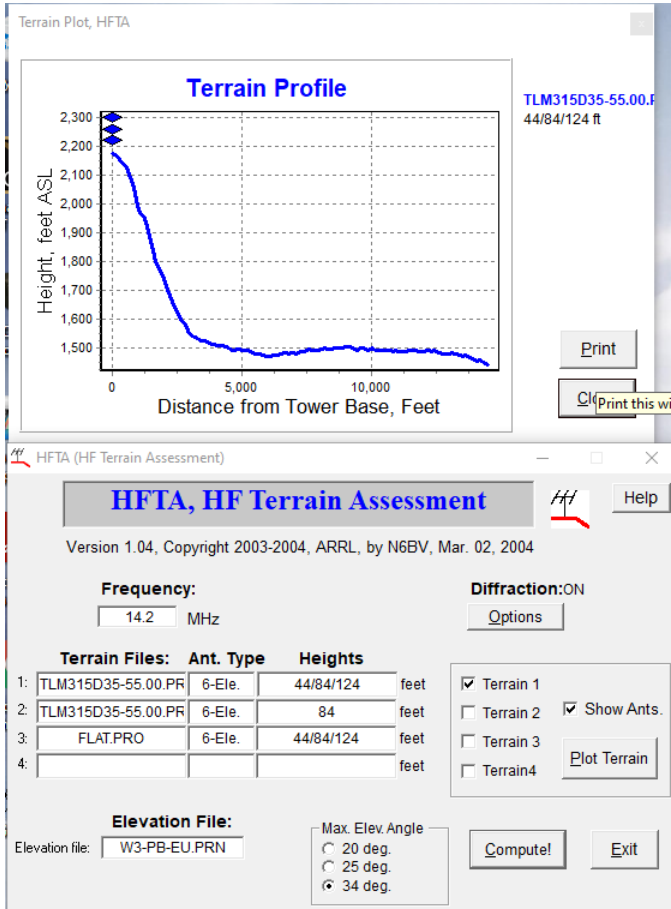


# Camp K – More Photos

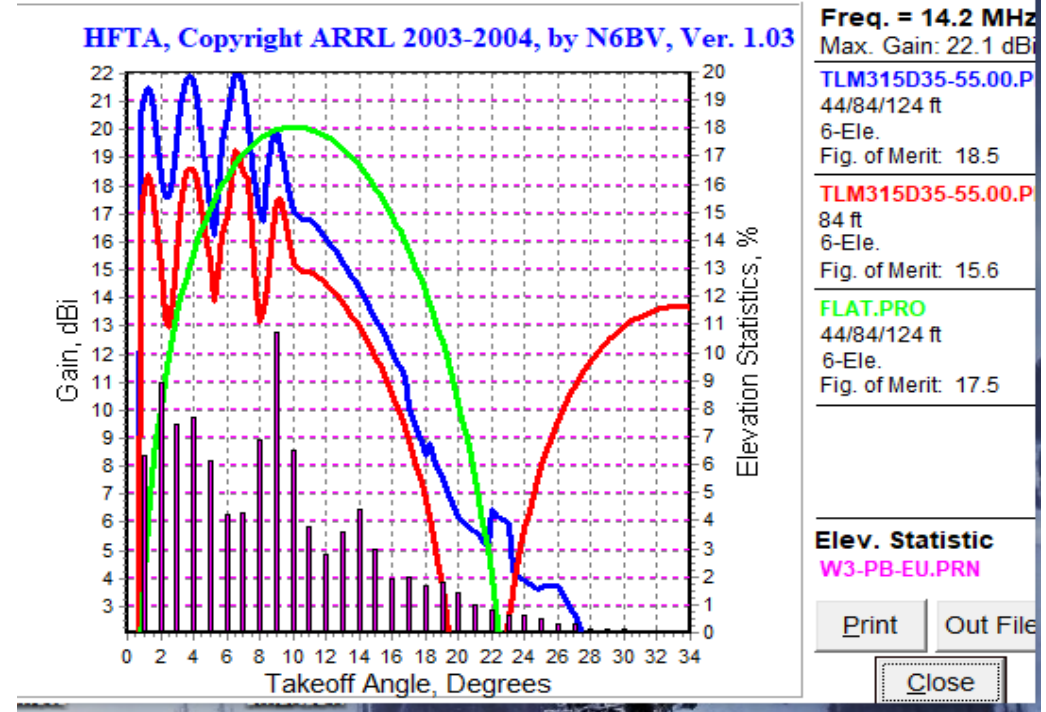




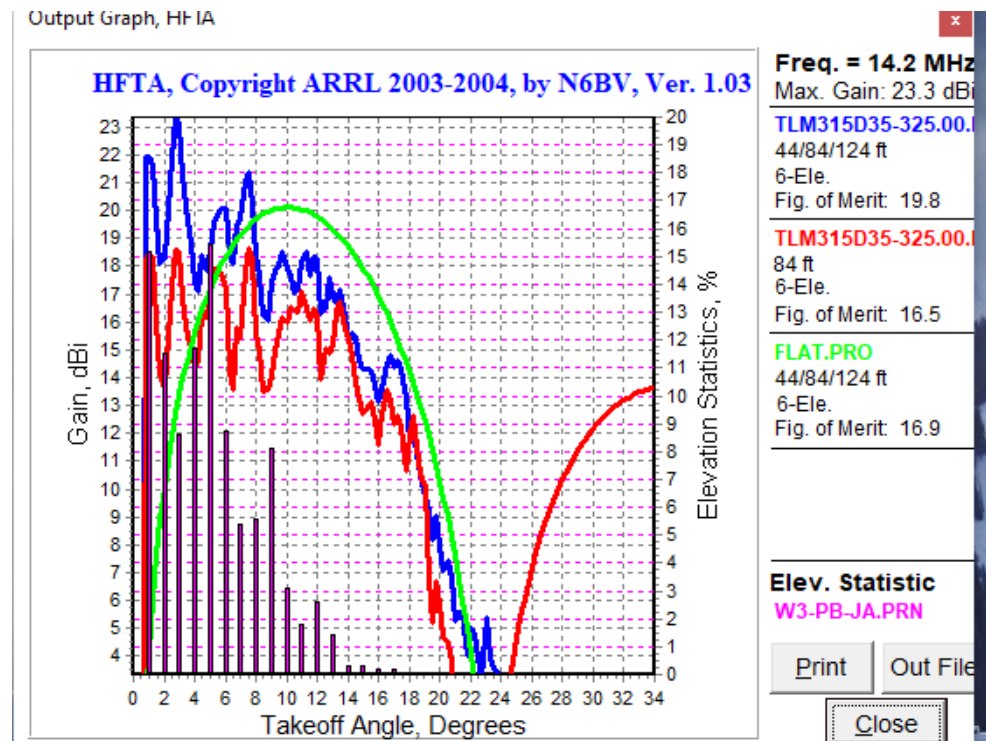
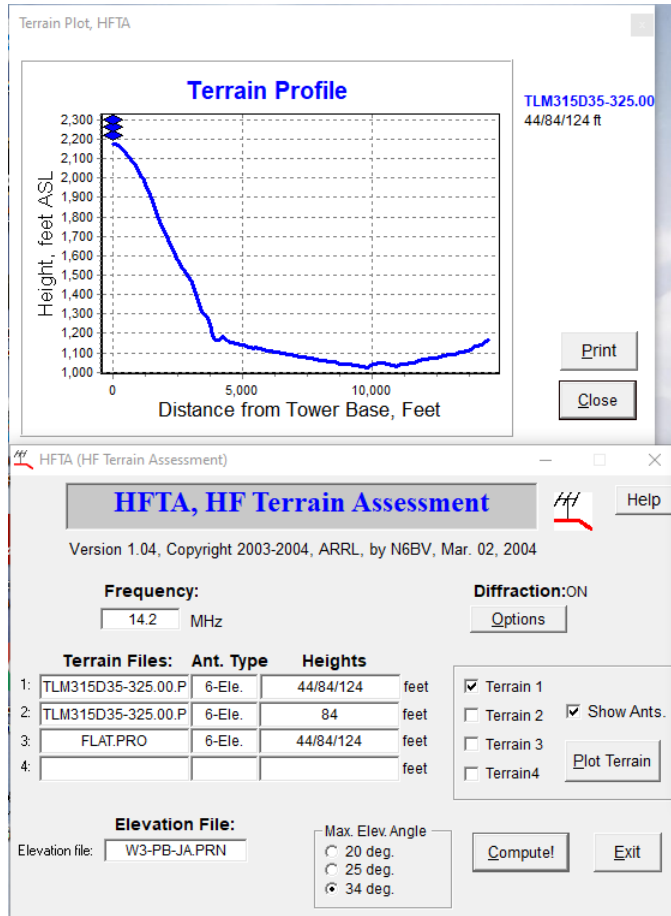
# Camp K 20m 6 Element Stack with HFTA Modeling from the Magic Mountain to Europe



Output Graph, HFTA



# Camp K 20m 6 Element Stack with HFTA Modeling from the Magic Mountain to Japan

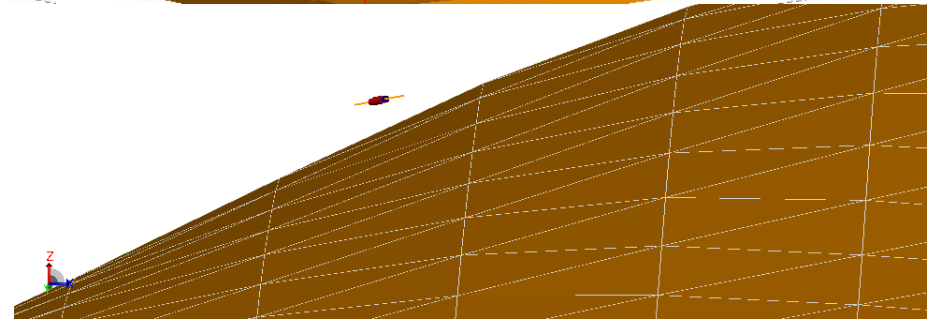
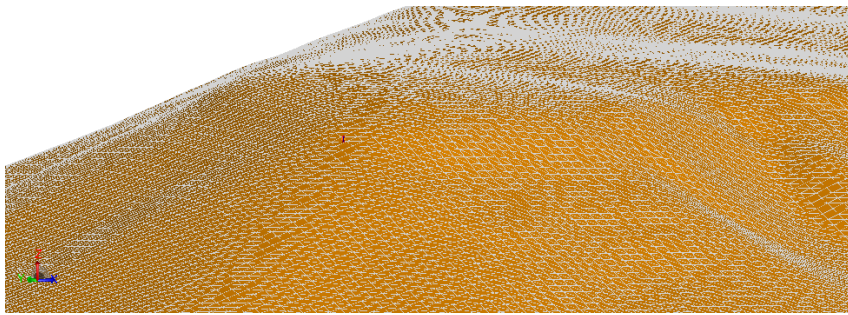
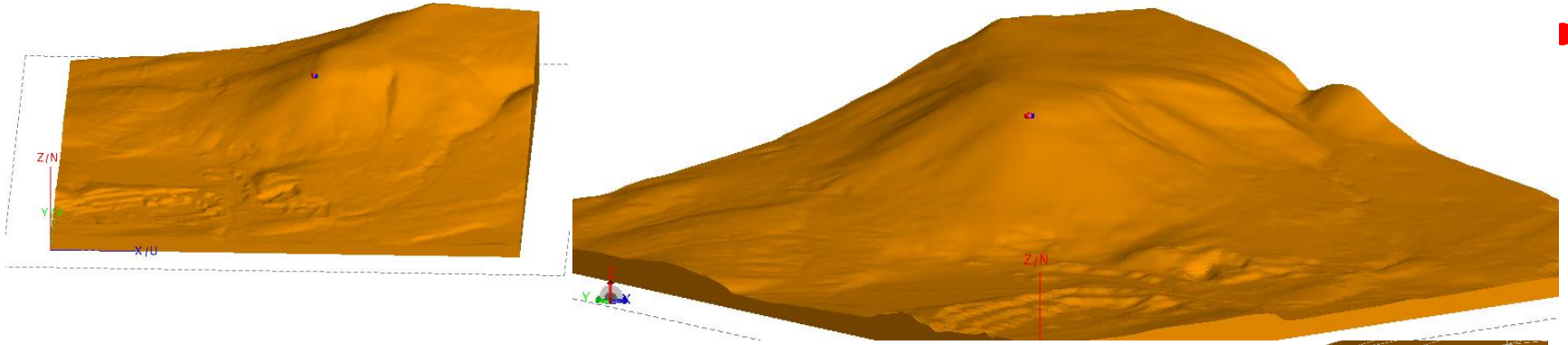


# Video of Magic Mountain

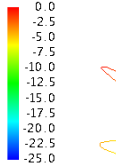


- Drone Flyover

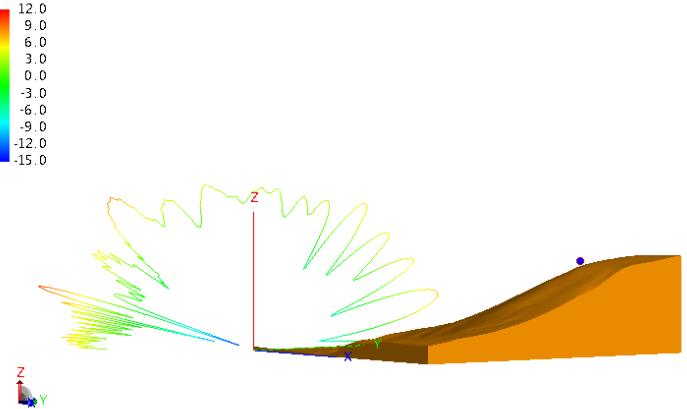
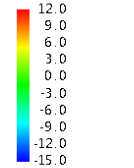
# The Future – 3D Terrain Modeling

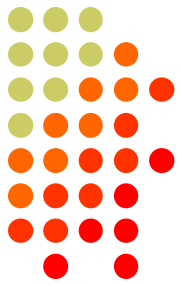


Total Gain [dBi]



Total Gain [dBi]







# Thank You!!!



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