An Introduction to HF System Design

Welcome to the wonderful world of HF!

By Dean Straw, N6BV

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The HF (High Frequency) Bands

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- Operating HF is intriguing, and fun!

4X4NJ on
160 meters

Communications

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- A transmitter, with a transmission line leading to an antenna
- A propagation medium
- A receiver, with a transmission line leading to an antenna.

HF Communications

- I will only talk here about antennas and the HF propagation medium -- the ionosphere.

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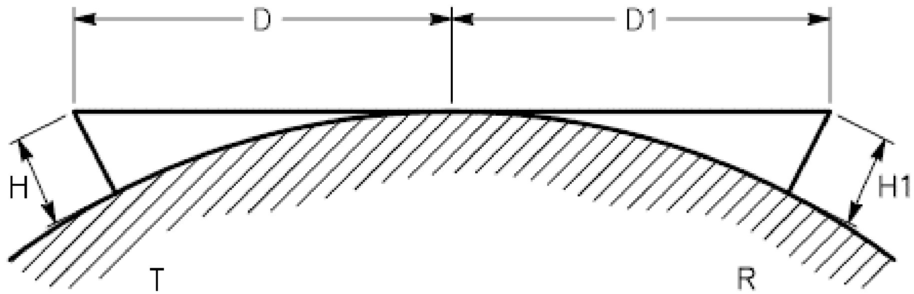
• You can communicate with *both* distant and local stations.

• Contrast VHF/UHF with HF: On VHF/UHF you generally only have local coverage -- often only through a repeater.

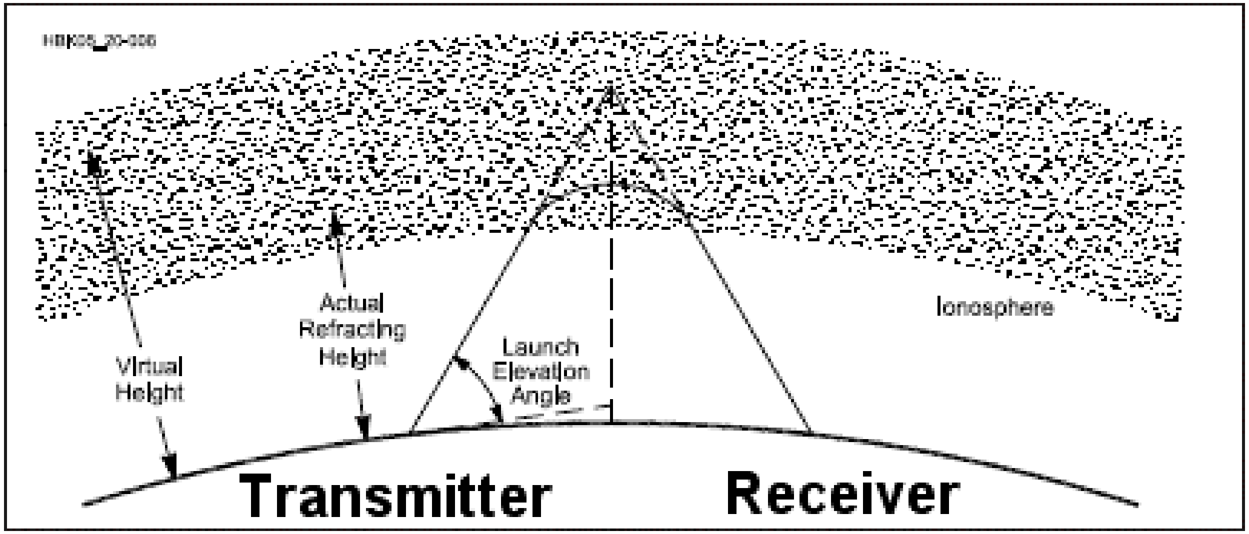
The Problem with VHF/UHF: Line-of-Sight Only Goes so Far as… well, Line-of-Sight



The Earth's curvature blocks direct signals.

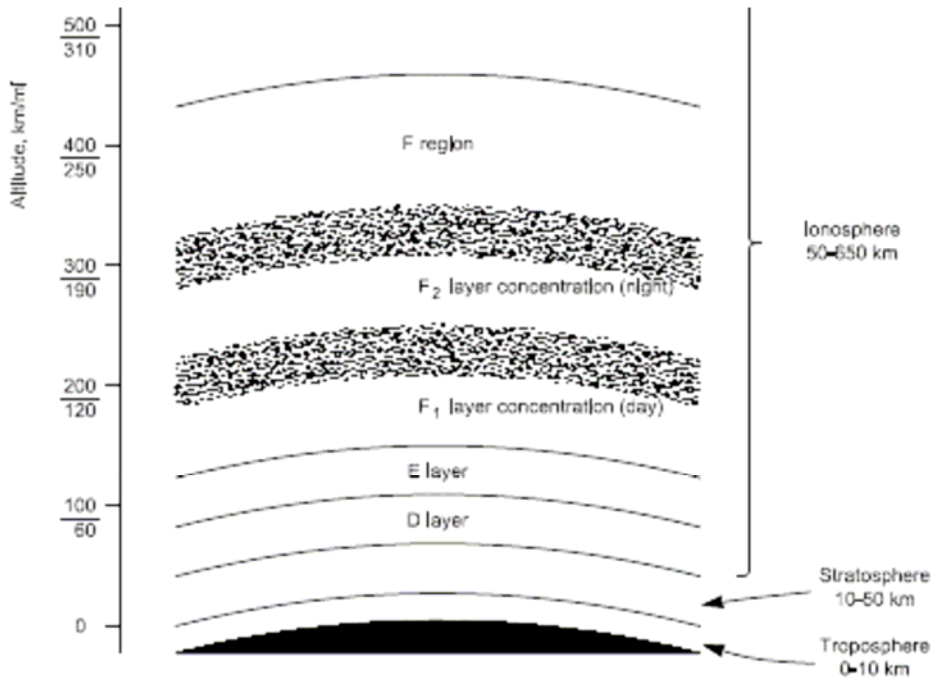
Courtesy *The ARRL Antenna Book*

Beyond Line-of-Sight



Beyond line-of-sight, you need a high reflector of some sort-- the Earth's ionosphere (or a satellite -- even the Moon).

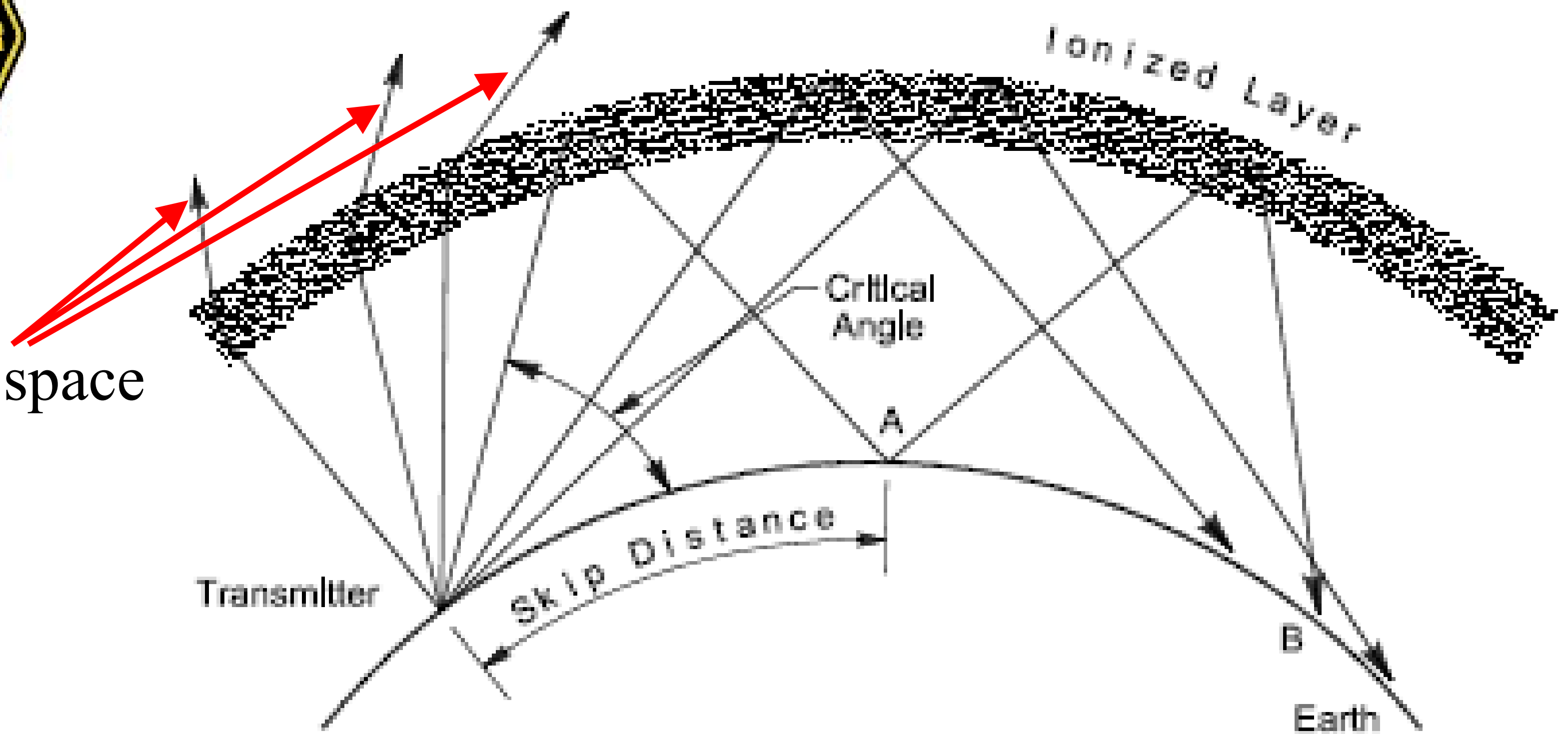
Regions in the Ionosphere



Solar excitation of trace elements creates ionized regions: D, E, F_1 and F_2. The F_2 region is the most important for long-distance HF communications.

Help from the Ionosphere

Lost to space



An ionized layer will refract signals back down to the Earth, if the level of ionization is sufficient. There is a *Critical Angle* for a particular level of ionization and layer height and frequency.

Courtesy *The ARRL Antenna Book*

State of the Ionosphere

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- Varies with the sun's 11-year cycle

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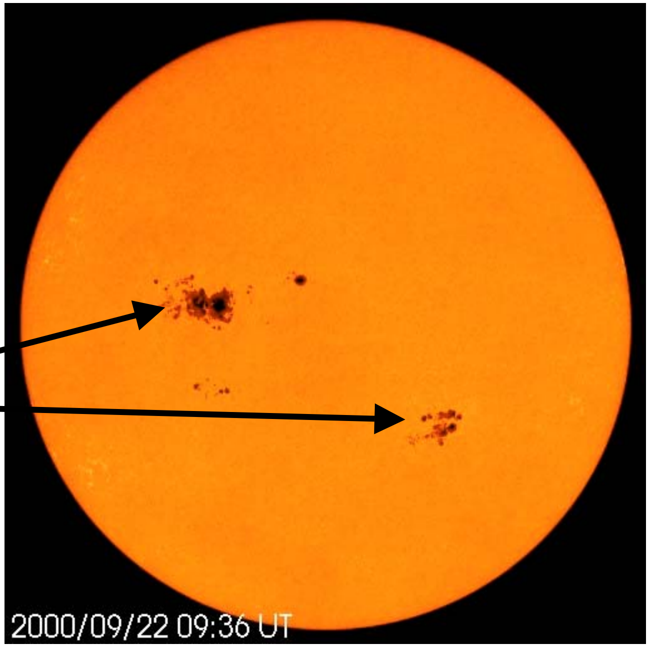
The level of ionization in the ionosphere varies with the state of the sun's production of UV:

- Varies with the sun's 11-year cycle
- Varies with the season (month and day)
- Varies with the hour (there's no solar UV at night, for example, in the area of darkness)

The Sun's Production of UV

The 14-30 MHz upper HF bands are most affected by the 11-year solar cycle: the number of sunspots vary over the cycle.

Lots of big sunspots in 2000



(Courtesy: NASA)

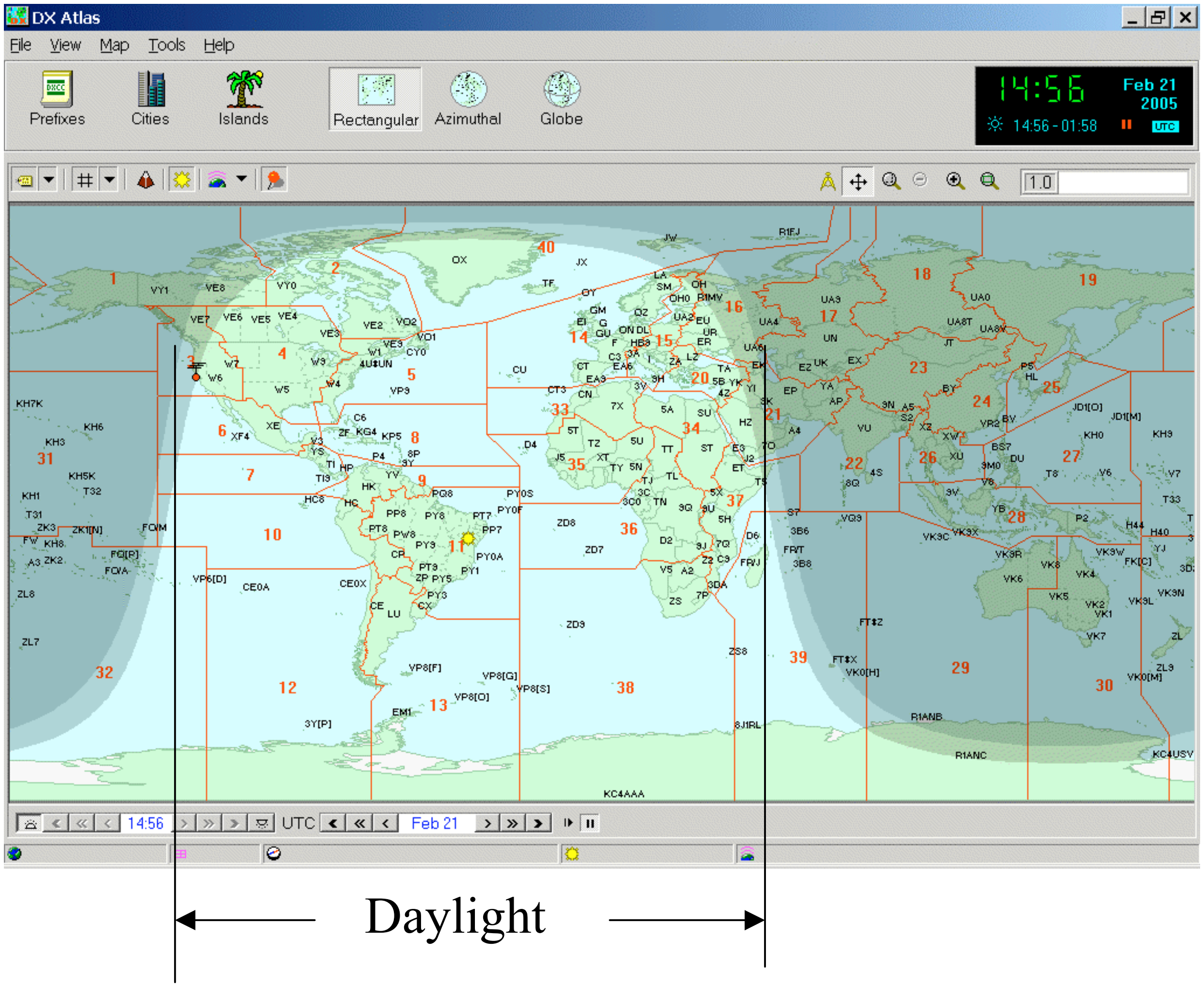
When there are sunspots, the Sun ionizes the ionosphere strongly with UV, promoting good propagation on the upper HF bands.

The Sun's Production of UV

(Courtesy: NASA)

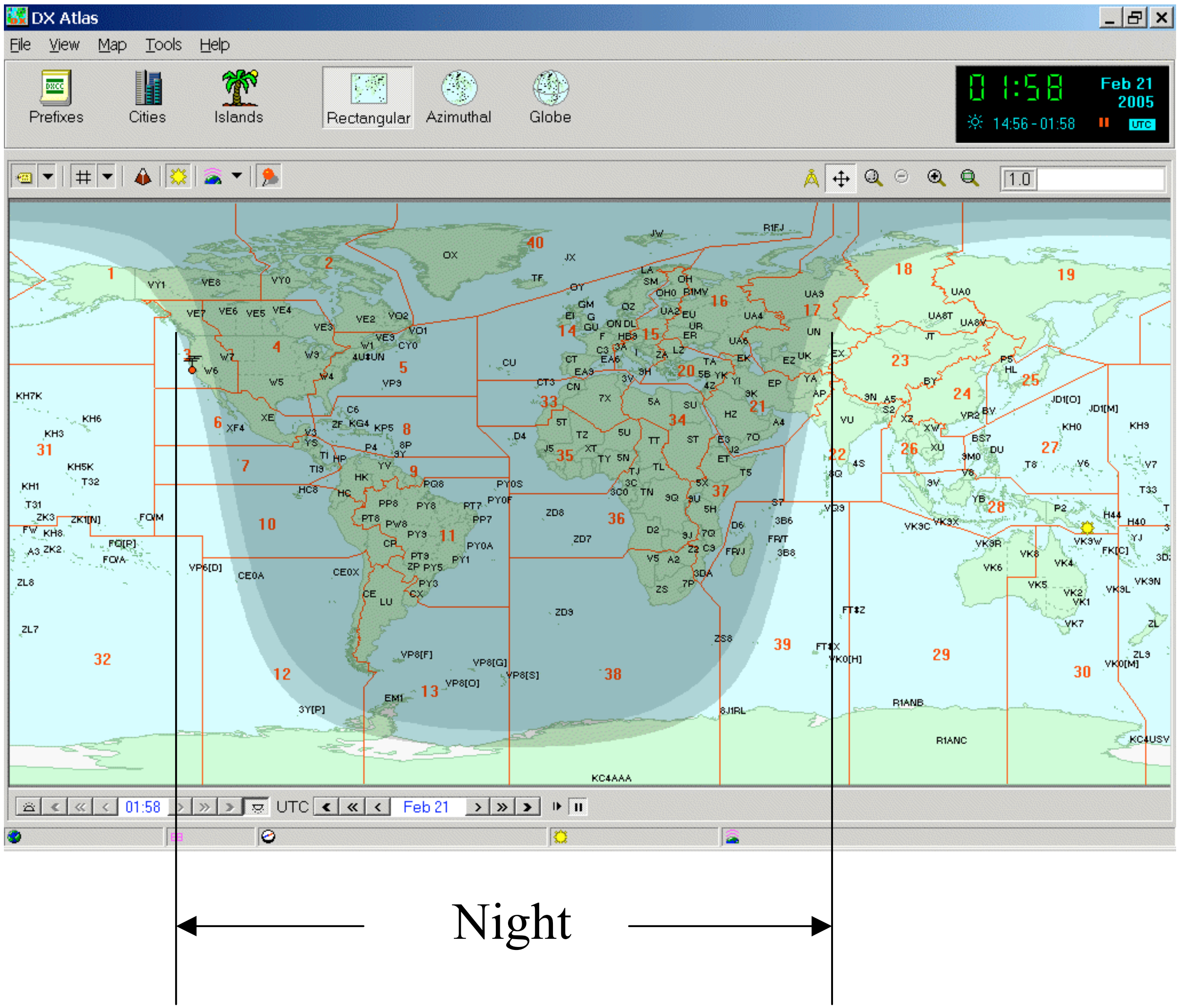
Right now we're well past the sunspot peak in Cycle 23. The upper HF bands are fairly quiet most of the time.

HF -- During the Day



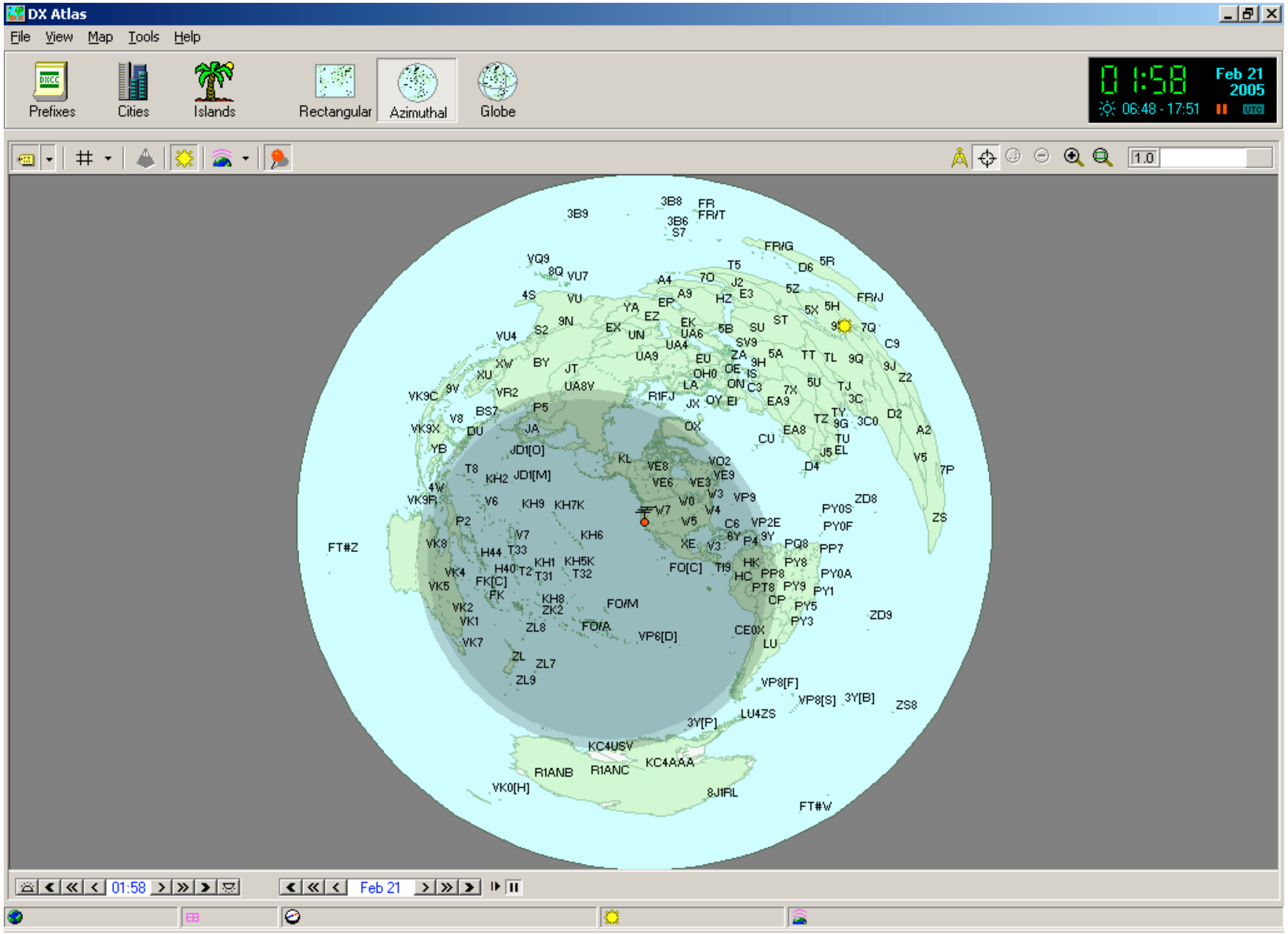
Upper HF bands (10-30 MHz) are open

HF -- At Night



Lower HF bands (2-10 MHz) are open

Azimuthal View -- Another Way to Look at the Earth



Doing HF

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- First, you can't do much to influence the sun!
- About the best you can do is pick an appropriate frequency and a time when a particular band is likely to be open.
- Then, you pick a suitable antenna, aim it at the desired station and try to make contact.

Explaining the Contest

- This audio snippet is from the 2001 ARRL Sweepstakes Contest, where the goal is to work as many people in the US and Canada in 24 hours.

- The information exchanged is rather long. For ex.: "Nr 144 Bravo N6BV 59 East Bay"

My call

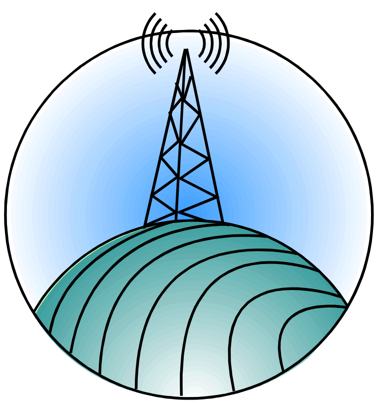
Serial no. Classification Year licensed ARRL location

Work 'em fast!

Scientifically Planning a Station

There are three elements needed to plan an HF station *scientifically*:

- The range of elevation angles needed.



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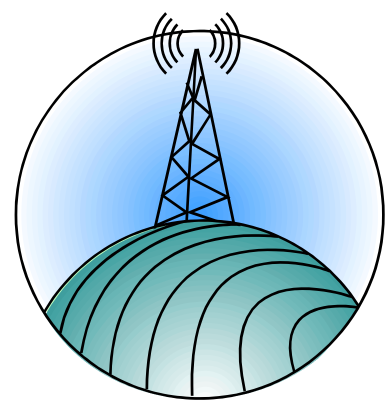
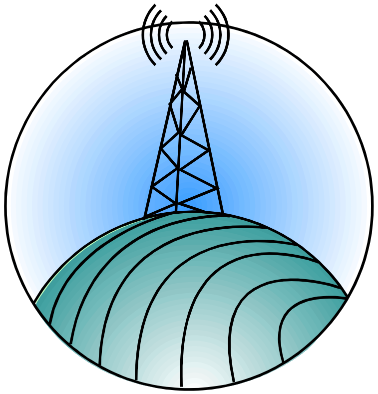


Scientifically Planning a Station

There are three elements needed to plan an HF station *scientifically*:

- The range of elevation angles needed.
- Antenna performance parameters.
- The effects of local terrain.



Elevation Angles

- About ten years ago I started a detailed study at ARRL HQ on the range of elevation angles needed for communication between various locations around the world.

- I used the *IONCAP* program (now upgraded to the *VOACAP* program), along with some proprietary software I wrote.

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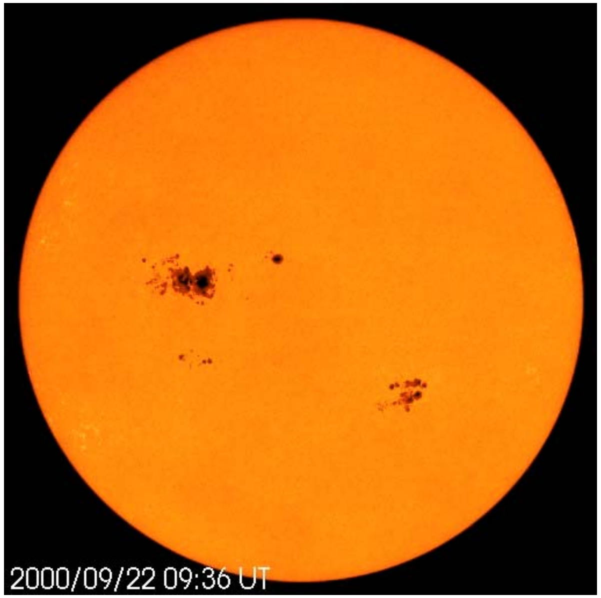
- The real world is *considerably* more complex. Statistical considerations prevail.
- There are numerous "exotic" propagation modes that make HF exciting -- and highly variable. This overview won't cover those.

What Angles Do You Need?

The elevation-angle files from *The ARRL Antenna Book* contain statistical averages over the entire 11-year solar cycle -- for all months of the year and for all hours of the day.



Sample Data, Boston to Europe

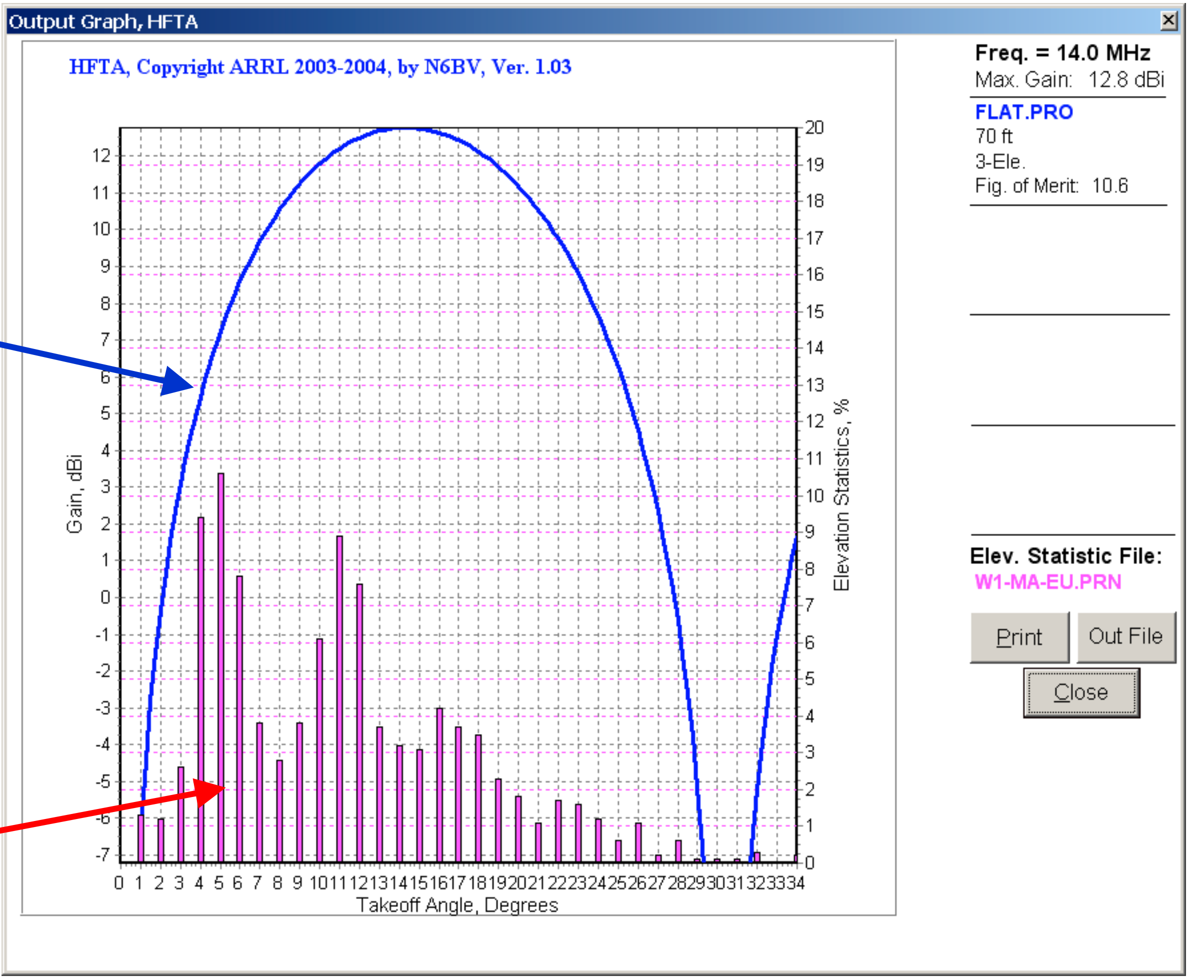
Boston, Massachusetts to Europe

Elev	80m	40m	30m	20m	17m	15m	12m	10m
1	4.1	9.6	4.6	1.7	2.1	4.4	5.5	7.2
2	0.8	2.3	7.2	1.4	2.8	2.8	3.7	5.3
3	0.3	0.7	4.3	3.1	2.4	2.2	4.4	7.9
4	0.5	4.1	8.7	11.6	12.2	9.4	8.1	3.9
5	4.6	4.8	7.5	12.7	14.3	13.1	9.2	11.2
6	7.1	8.9	5.5	9.2	9.6	12.2	9.2	7.2
7	8.5	6.9	7.2	4.6	7.9	7.4	10.0	5.9
8	5.1	7.0	5.4	3.2	5.9	7.4	4.8	6.6
9	3.3	5.6	3.2	3.1	2.1	3.9	8.1	9.2
10	1.0	4.0	7.9	6.3	5.1	3.7	11.1	6.6
11	1.9	3.8	9.7	10.2	7.2	5.4	3.7	7.9
12	5.6	3.4	4.8	8.5	6.9	7.4	4.8	6.6
13	11.0	3.0	2.4	4.1	5.9	4.6	3.3	2.6
14	7.6	4.8	2.0	2.7	3.8	3.9	6.3	5.9
15	5.3	7.9	2.0	1.5	2.4	1.7	1.5	2.0
16	2.8	6.4	3.8	2.9	1.5	1.3	2.6	2.6
17	5.0	3.4	4.5	3.1	1.0	1.5	0.0	0.0
18	4.2	2.0	3.1	3.1	2.0	2.2	1.8	1.3
19	5.7	1.4	1.4	2.3	1.3	0.7	0.0	0.0
20	6.6	1.4	1.2	1.8	1.1	1.3	0.7	0.0
21	4.4	1.4	0.5	0.8	0.7	0.7	0.4	0.0
22	2.3	2.4	1.0	1.1	0.6	1.3	0.7	0.0
23	1.3	1.8	0.1	0.3	0.1	0.0	0.0	0.0
24	0.6	1.0	0.5	0.5	0.4	0.7	0.0	0.0
25	0.3	0.8	0.3	0.1	0.4	0.0	0.0	0.0
26	0.0	0.5	0.7	0.2	0.1	0.4	0.0	0.0
27	0.1	0.1	0.1	0.2	0.1	0.2	0.0	0.0
28	0.0	0.3	0.1	0.2	0.0	0.2	0.0	0.0
29	0.1	0.0	0.2	0.0	0.0	0.0	0.0	0.0
30	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0

One Picture is Worth a Thousand Words

Elevation response of 3-element Yagi at 70’ over flat ground

Elevation-angle stats



The Basics of Antennas

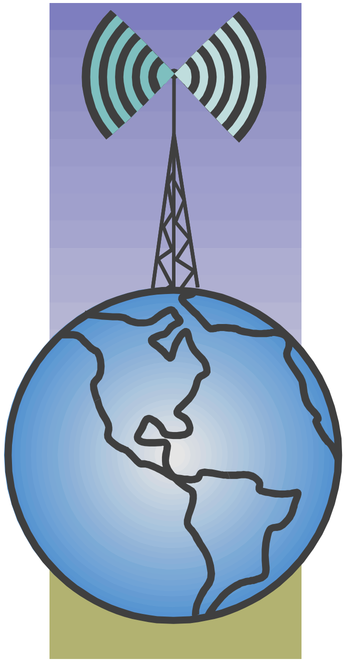
An antenna is a *transducer.*

Here's a transducer you all have seen and heard: a *loudspeaker*.

A loudspeaker converts electrical energy into mechanical energy -- that is, into sound waves.

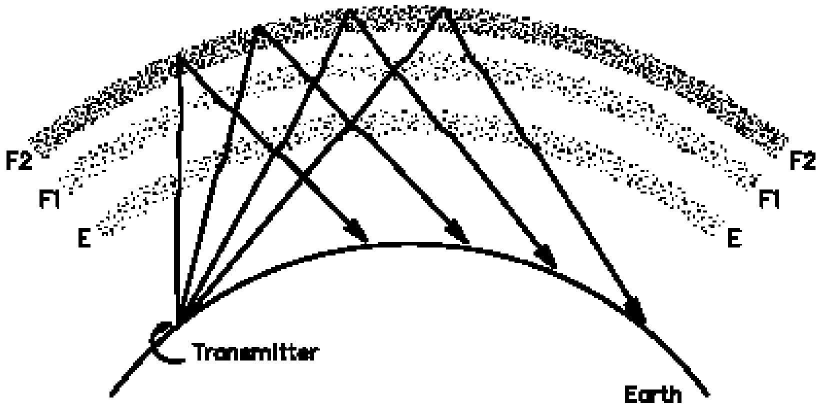
Antenna as Transducer

- Like a loudspeaker, an antenna acts like a transducer, but it converts electrical energy to *electromagnetic waves*.



Electromagnetic Waves

- Unlike sound waves, electromagnetic waves don't require a medium for transmission. They can travel in the vacuum of outer space or in the ionosphere.



Electromagnetic Waves

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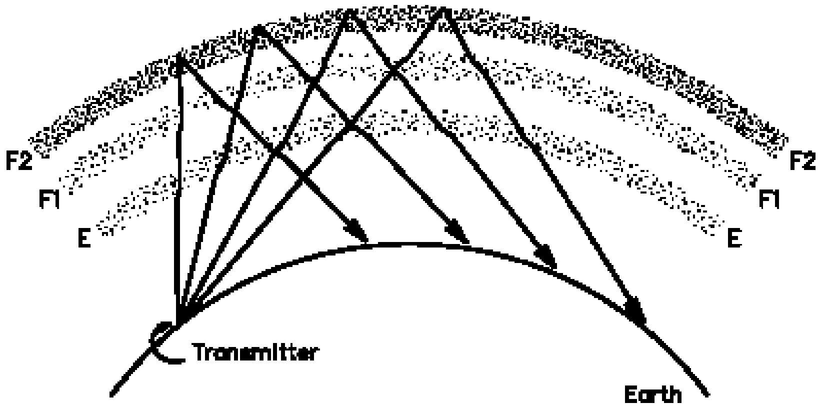
• That they *do* travel in the ionosphere is part of the magic and wonder of radio -- because some waves manage to come down to earth, far away.



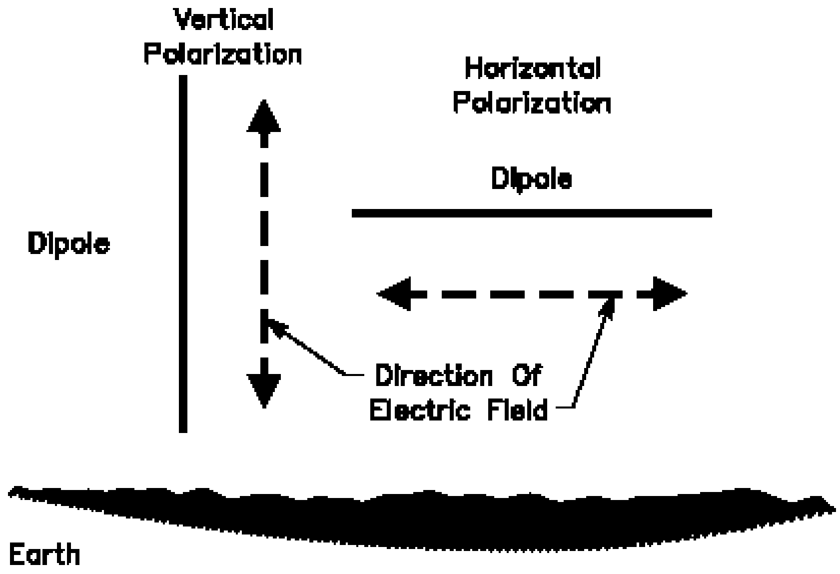
Antenna Characteristics

- **Polarization**
- **Gain**
- **Feed-Point Impedance**

Polarization

• Defined as the direction of the *electric field* of an electromagnetic wave.

• Over ground, a horizontal dipole is horizontally polarized. A vertical dipole is vertically polarized.



Polarization

• Ionospheric propagation jumbles polarization so an antenna's polarization isn't important.

• Ground losses with vertically polarized antennas can be severe, however. More on this later.

Antenna Gain

- ***Gain*** **compares an antenna to a reference** ***isotropic*** **antenna.**

An isotropic antenna radiates equally well in all directions. (Professor Leeson likens this to the sun.)

Antenna Gain

- ***Gain* compares an antenna to a reference *isotropic* antenna.**

An isotropic antenna radiates equally well in all directions. (Professor Leeson likens this to the sun.)

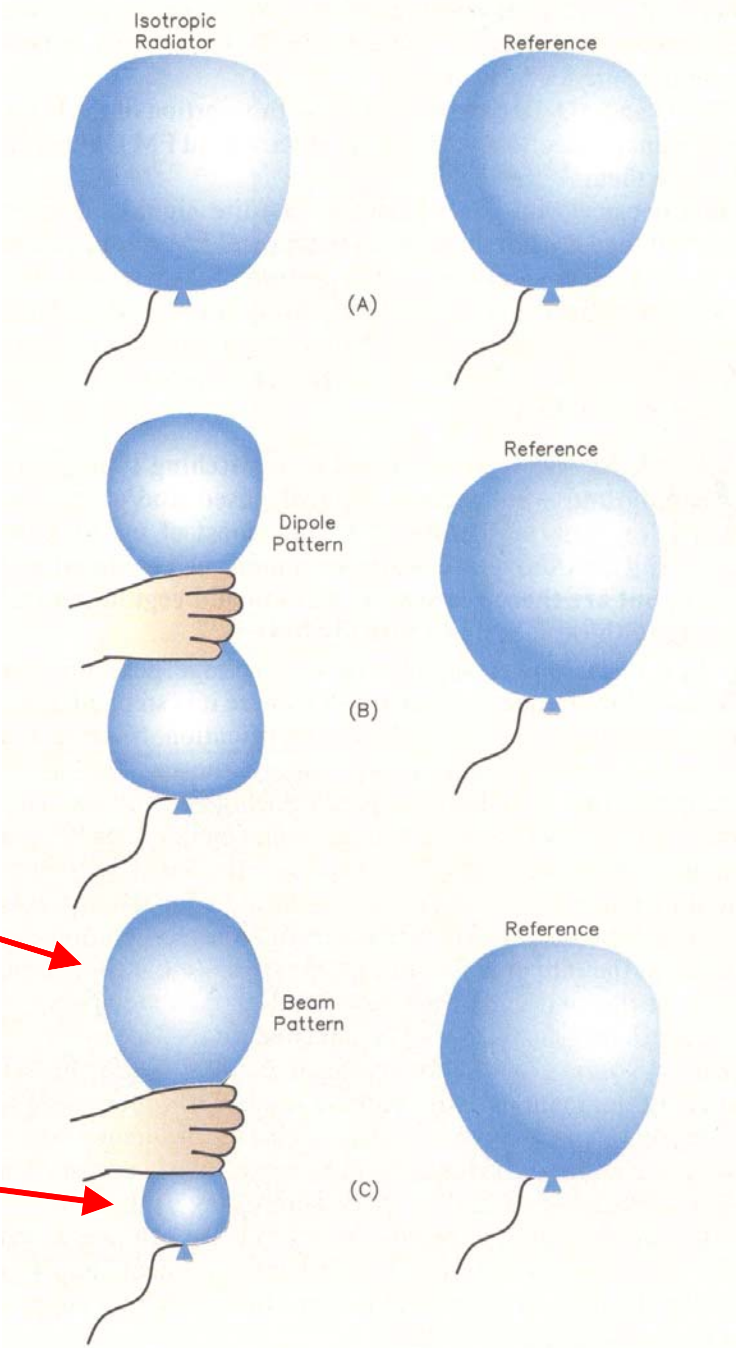
- **You don't get something for nothing.**

Having *more* signal in one direction (gain) means *less* signal in other directions.

Antenna Gain

Like squeezing a balloon...

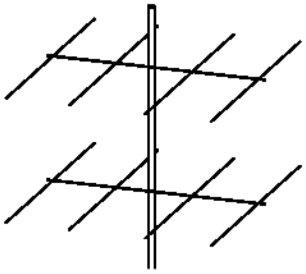
More signal in one direction means less signal in other directions



Antenna Gain

The range of HF antenna gain is not that large -- from about –10 to +20 dBi.

• This 30-dB range covers antenna ranging from a radiating light bulb (!) up to a stack of Yagis.



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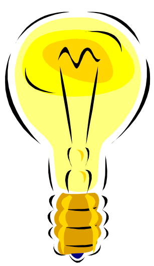
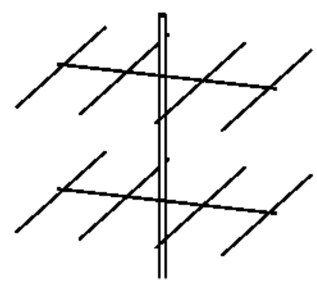


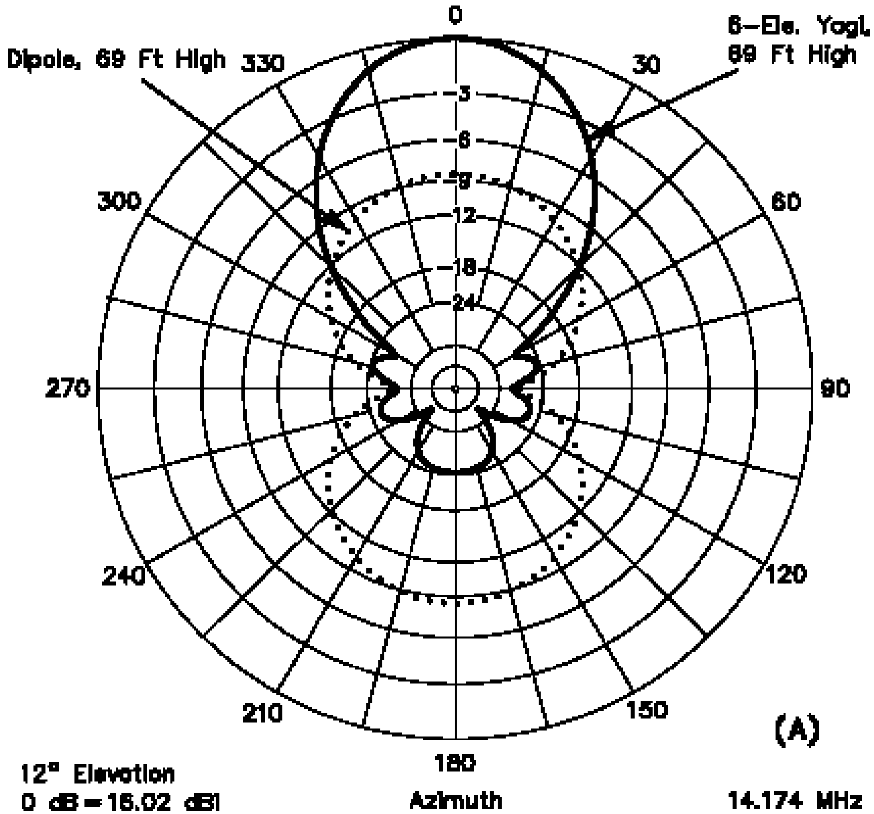


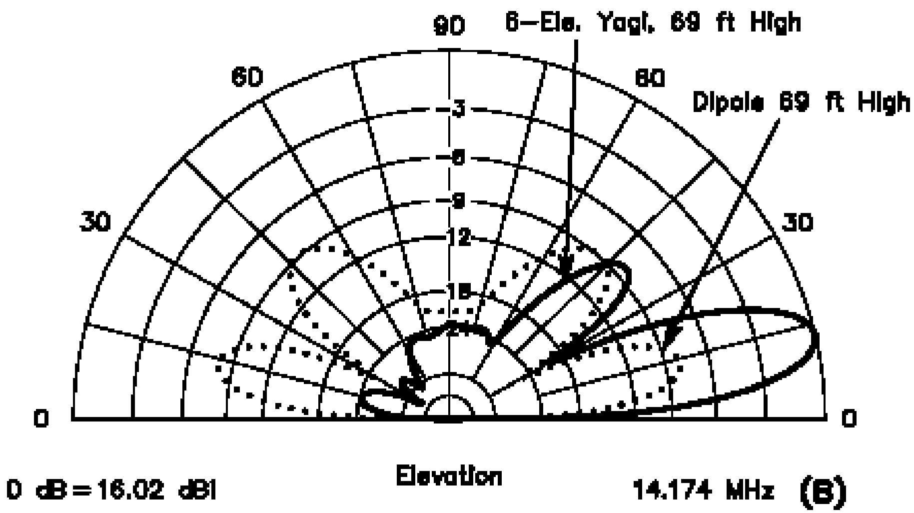
• It's like going from 1 W to 1000 W, or about 5 S-units on a typical communications receiver.

Antenna Gain

You will hear much about azimuth and elevation patterns.

Azimuth

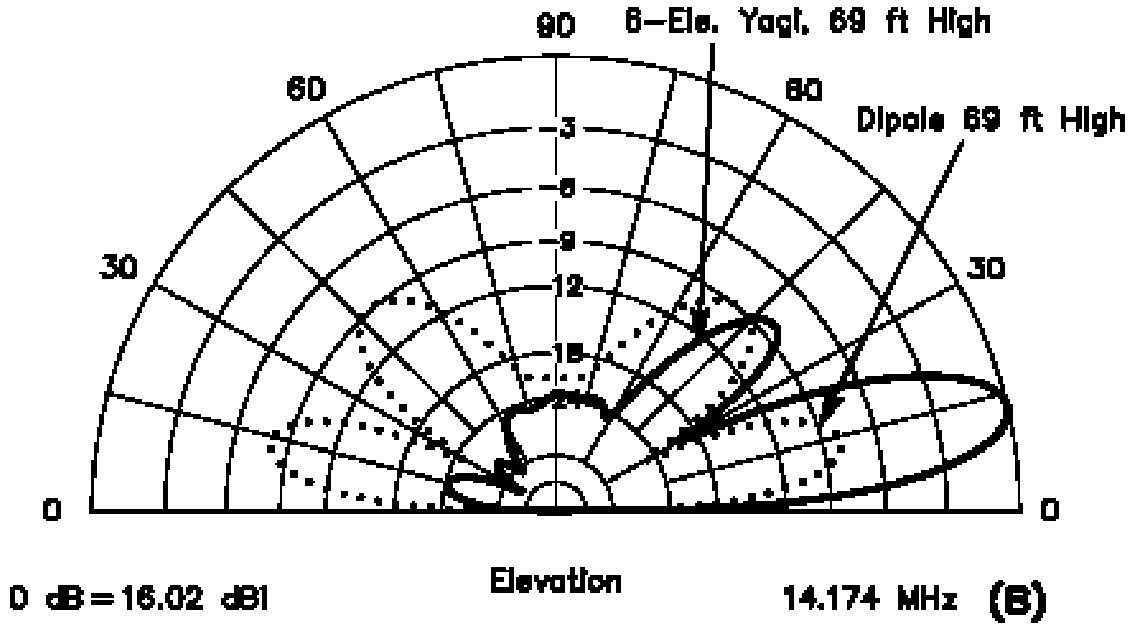




Elevation

Elevation-Plane Pattern

For a horizontally polarized antenna, the *height* directly affects the elevation pattern.



Over flat ground.

Feed-Point Impedance

- It's just what it says -- the impedance measured at the antenna's feed point.

Prototypical half-wave dipole

Feed-Point Impedance

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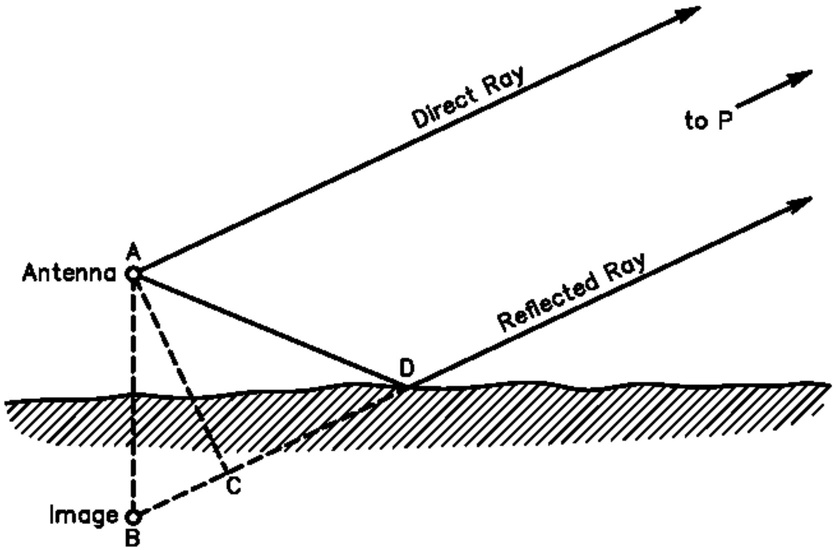
- Most hams are accustomed to seeing feed-point impedance expressed as an SWR (standing-wave ratio) referenced to a feed line's characteristic impedance (often, 50 Ω).
- An antenna need not be *resonant* to be an efficient radiator -- but a resonant antenna is easier to match to provide a 1:1 SWR to the transmitter -- that is, $50 + j\,0\ \Omega$.

The Antenna's Environment

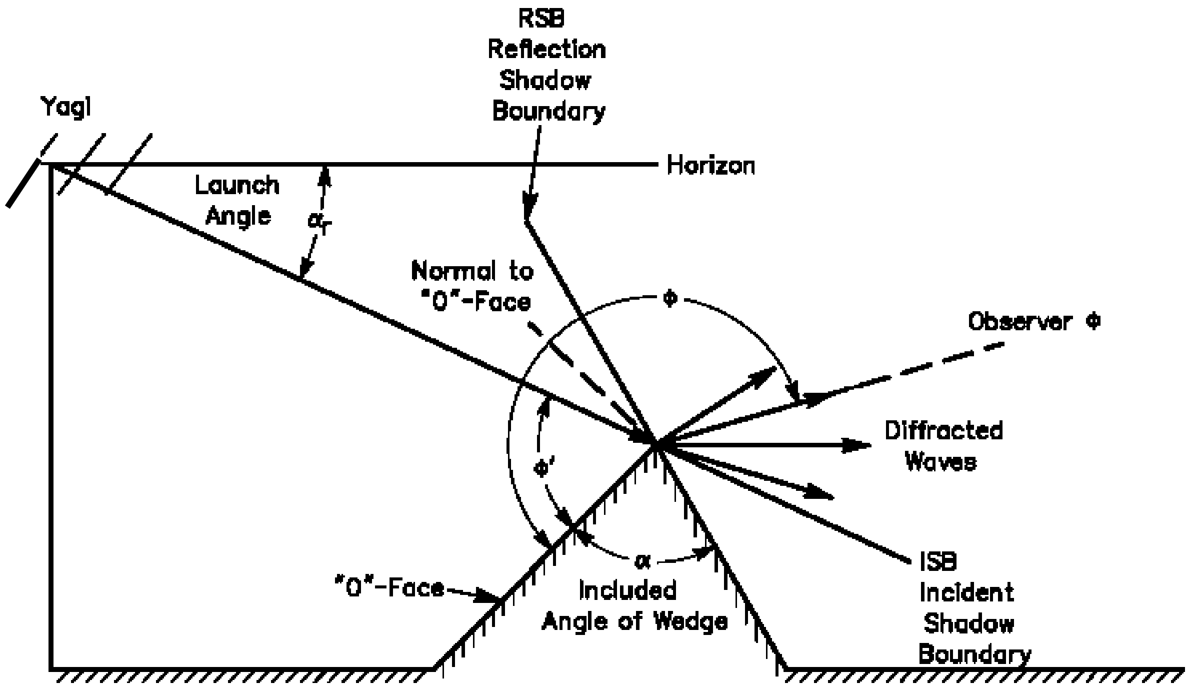
- The most obvious environment lies underneath an antenna -- the *ground*.
- Flat ground is easy to analyze mathematically.
- Local terrain is rarely perfectly flat!



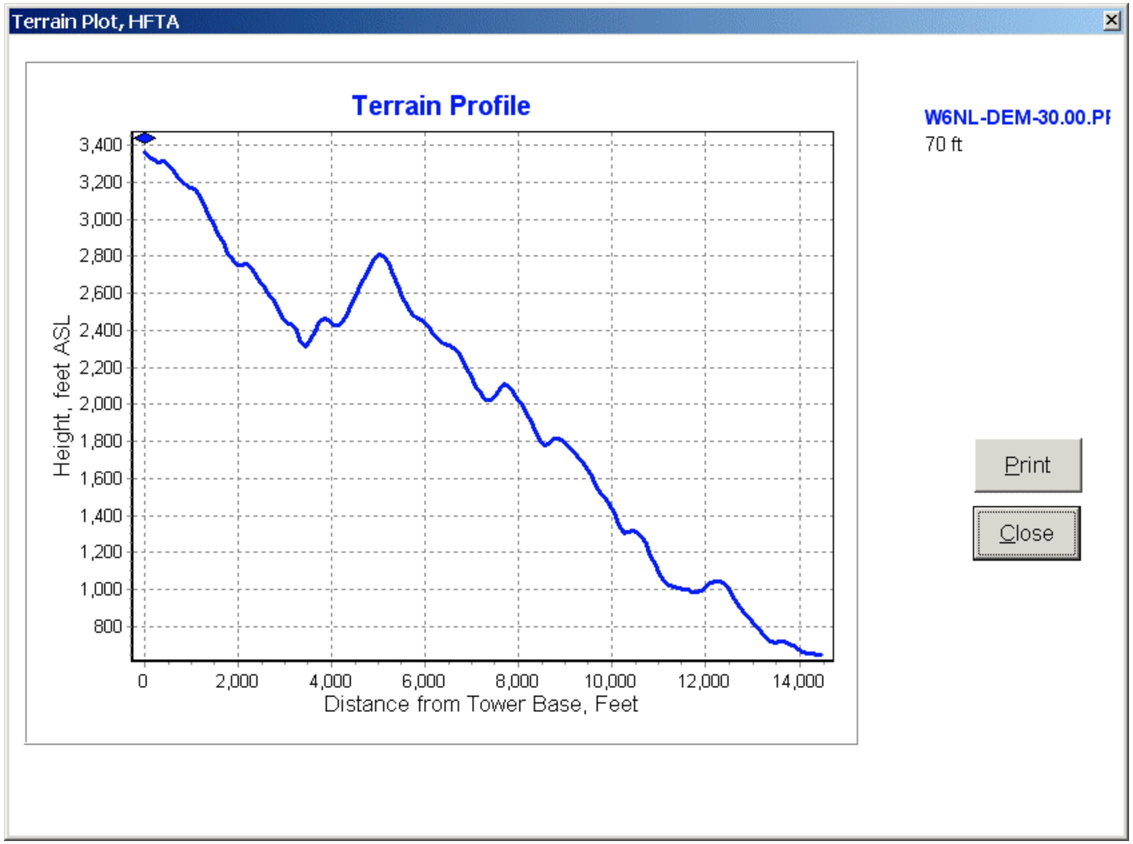
Theory of images can be used to analyze the flat-ground case.

Local Terrain

• Local terrain, however, can have a profound effect on the launch of HF signals. *Diffraction* and reflection make things very complex.

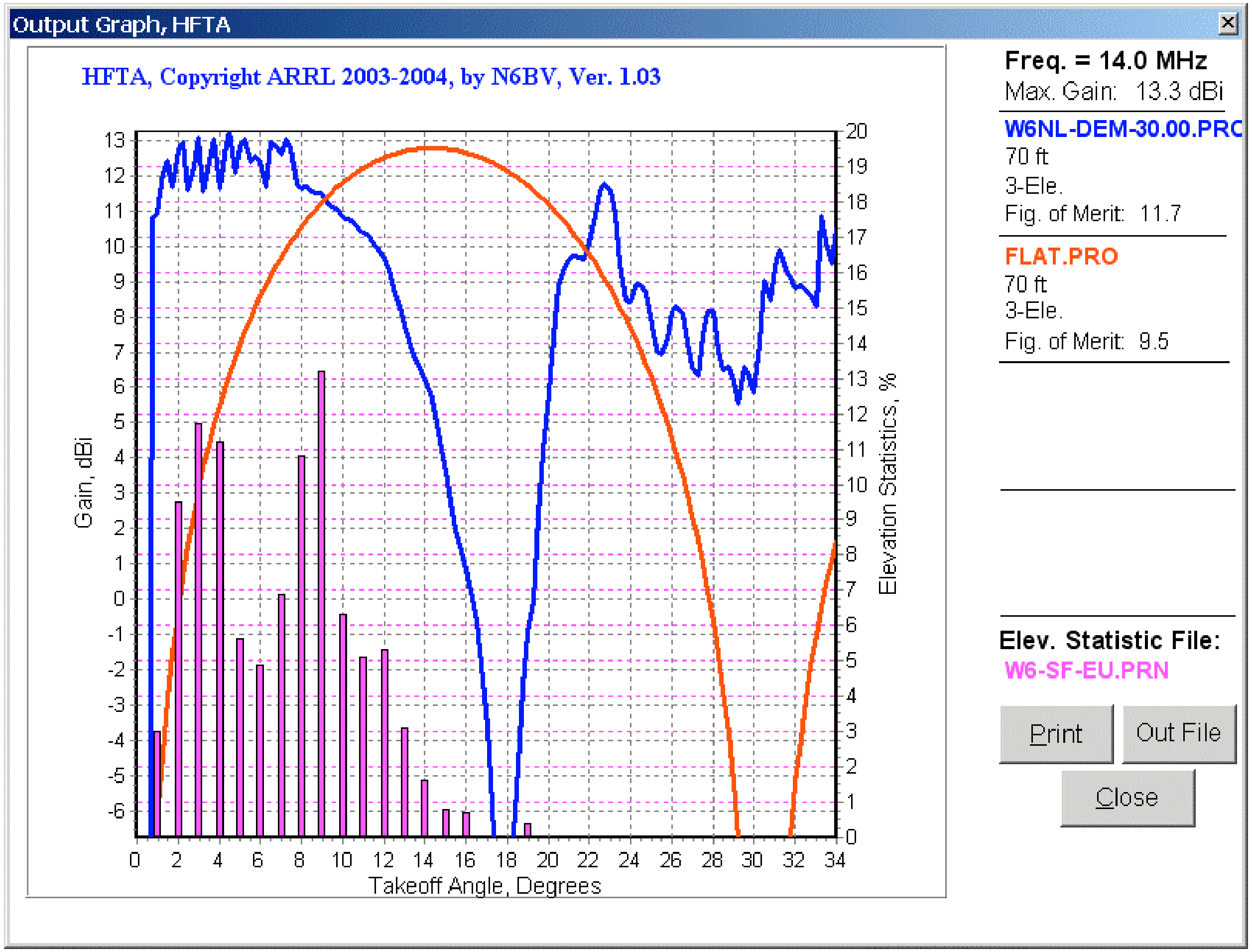


Local Terrain, an Example



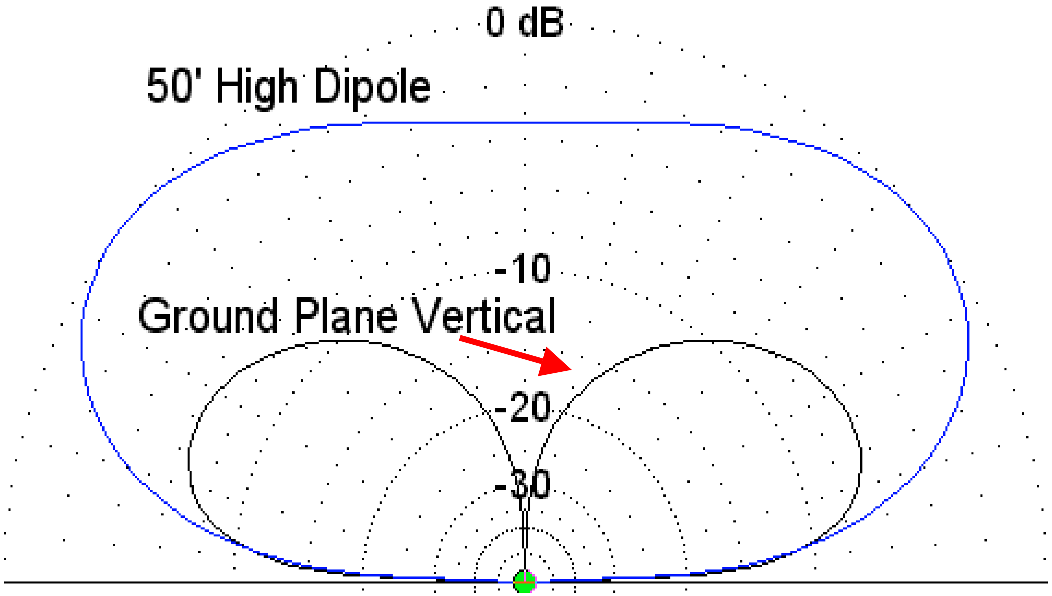
Terrain at Dr. Leeson's (W6NL) place, towards Europe

Local Terrain



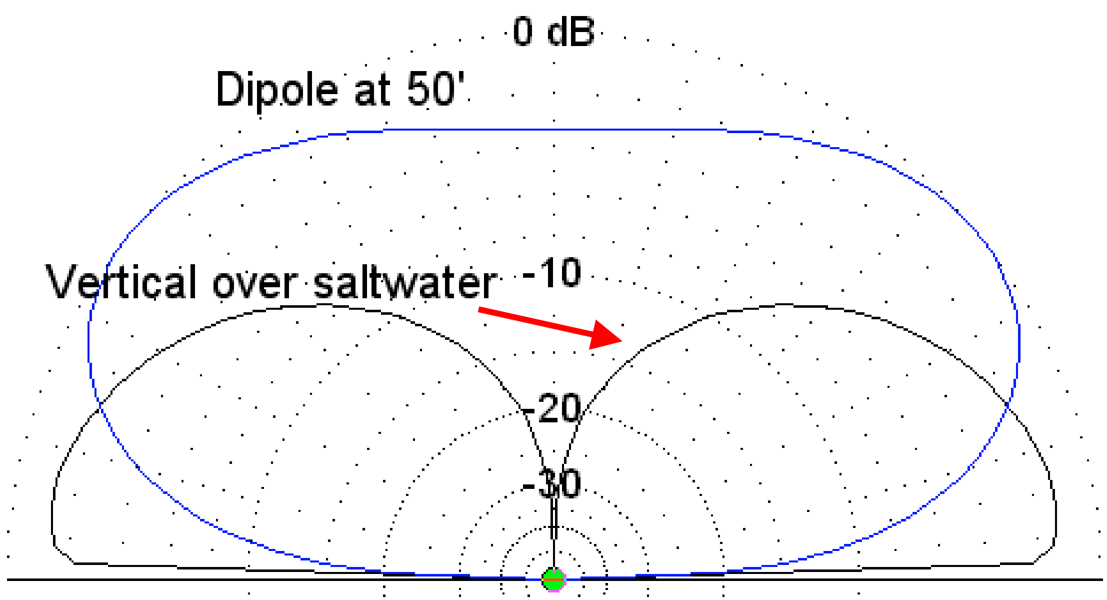
For more details on local terrain, see *The ARRL Antenna Book*.

Horizontal vs Vertical



Over "typical" soil, a vertical will lose out to a 50-foot high horizontal dipole.

Put that Vertical at the Seashore, However...



Now we have a real horse race, especially at low elevation angles!

In Summary

- Is it really necessary to have detailed knowledge of the ionosphere, your antenna and the local terrain to have fun on HF?

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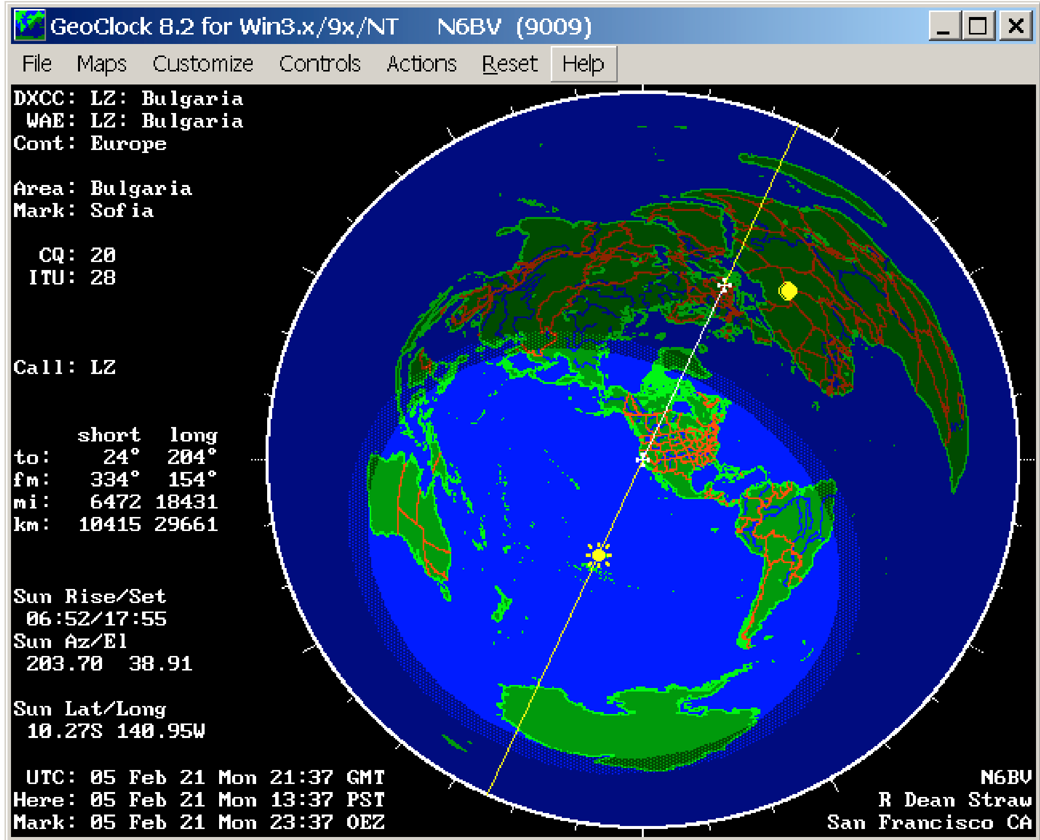
- Is it really necessary to have detailed knowledge of the ionosphere, your antenna and the local terrain to have fun on HF?
- Absolutely not! You can talk to people all around the world by flinging a wire dipole into the trees and getting on the air.



- But to someone trained as an engineer, it’s much more gratifying to plan things a little more scientifically!