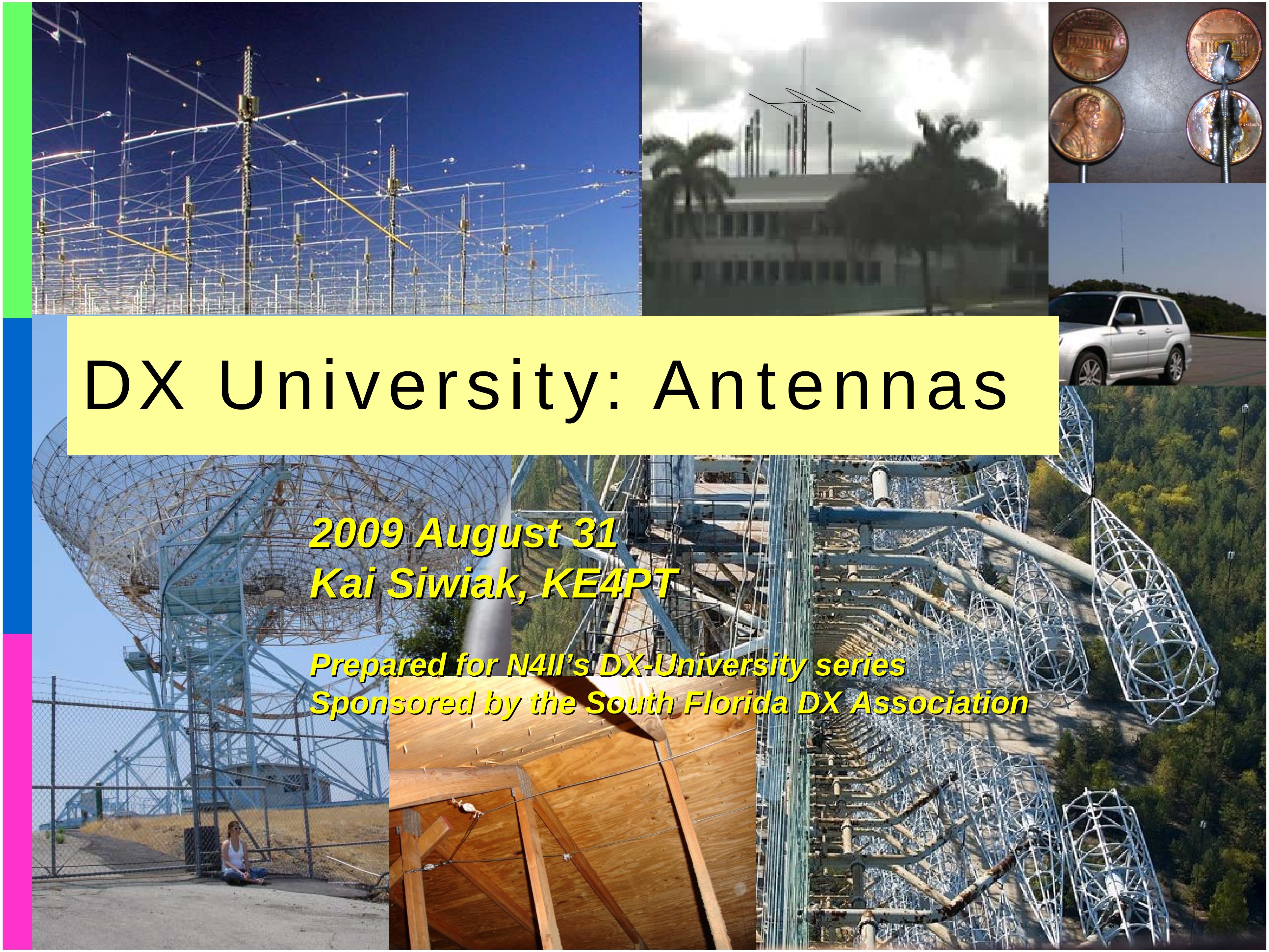


DX University: Antennas

2009 August 31
Kai Siwiak, KE4PT

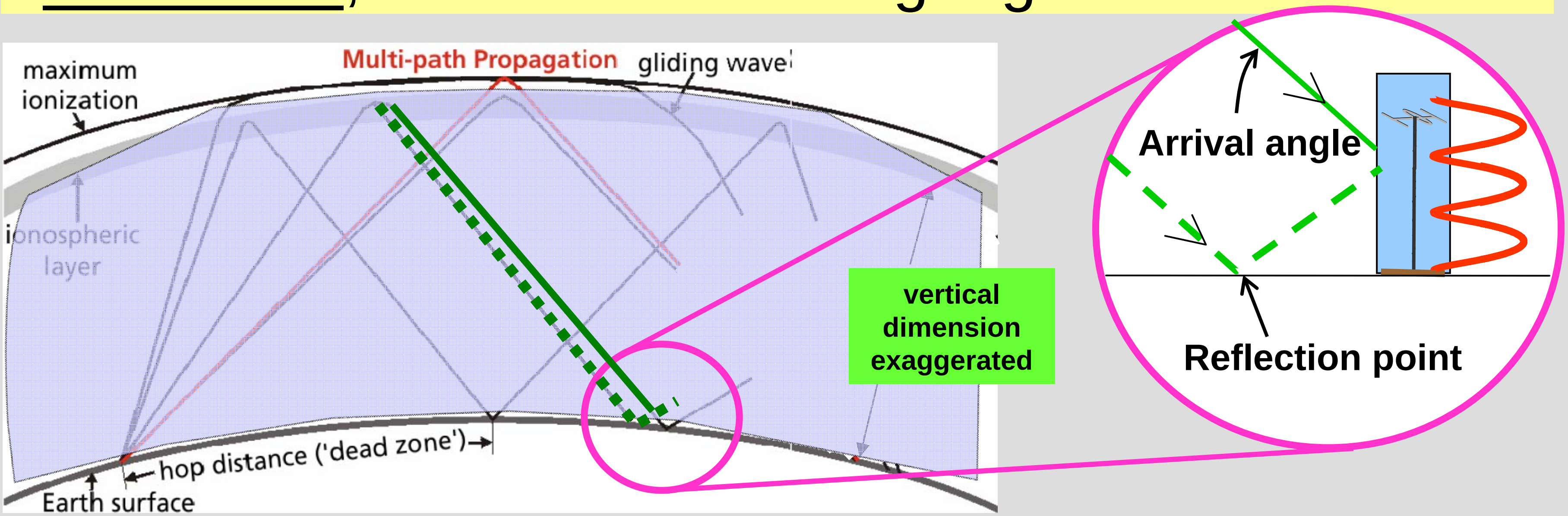
Prepared for N4II's DX-University series
Sponsored by the South Florida DX Association

No Antenna Theory, Just Results

- **What does it take to work DX?**
  - **Where you place the antenna matters because signals vary with height**
- **We want to know how well different ham antenna systems perform**
  - **Yagis / Quads on Towers**
  - **Mobiles and Verticals**
  - **Indoor Antennas and Wire Simple Antennas**
- **About RF Exposure and Antenna Safety**
- **Antenna Modeling**

Why Signal Strength Varies with Antenna Height

- Ground reflections cause vertical <u>STANDING WAVE PATTERN</u>, or variation in "height gain"

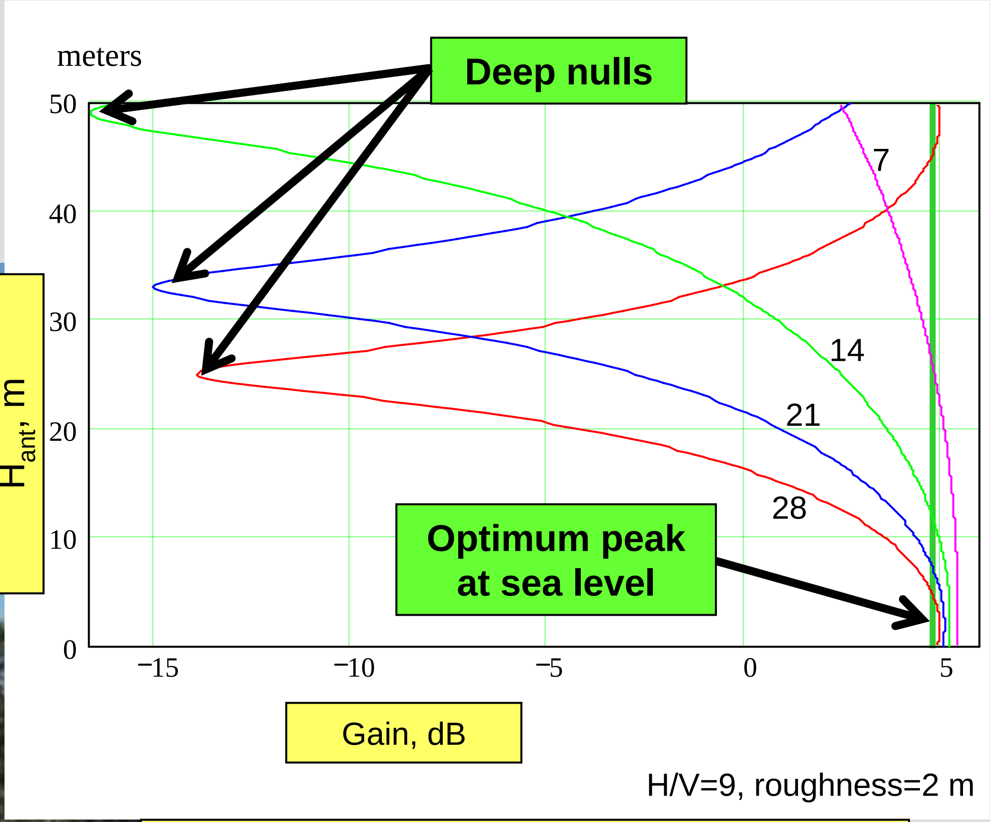


- <u>Vertical Standing Wave</u> means there is an Optimum Height for Antennas

<u>Stay tuned</u>: Propagation will be covered in Session #5

Vertical Polarization: "The Reflection Point is Sea Water"

- Vertical polarization: over *sea water* like (VP6DX)
- ***optimum is at sea level***



"0 dB" reference is free space (no ground reflection)

Source: VP6DX Ducie Antennas: http://www.youtube.com/watch?v=rwtZBtHJTew

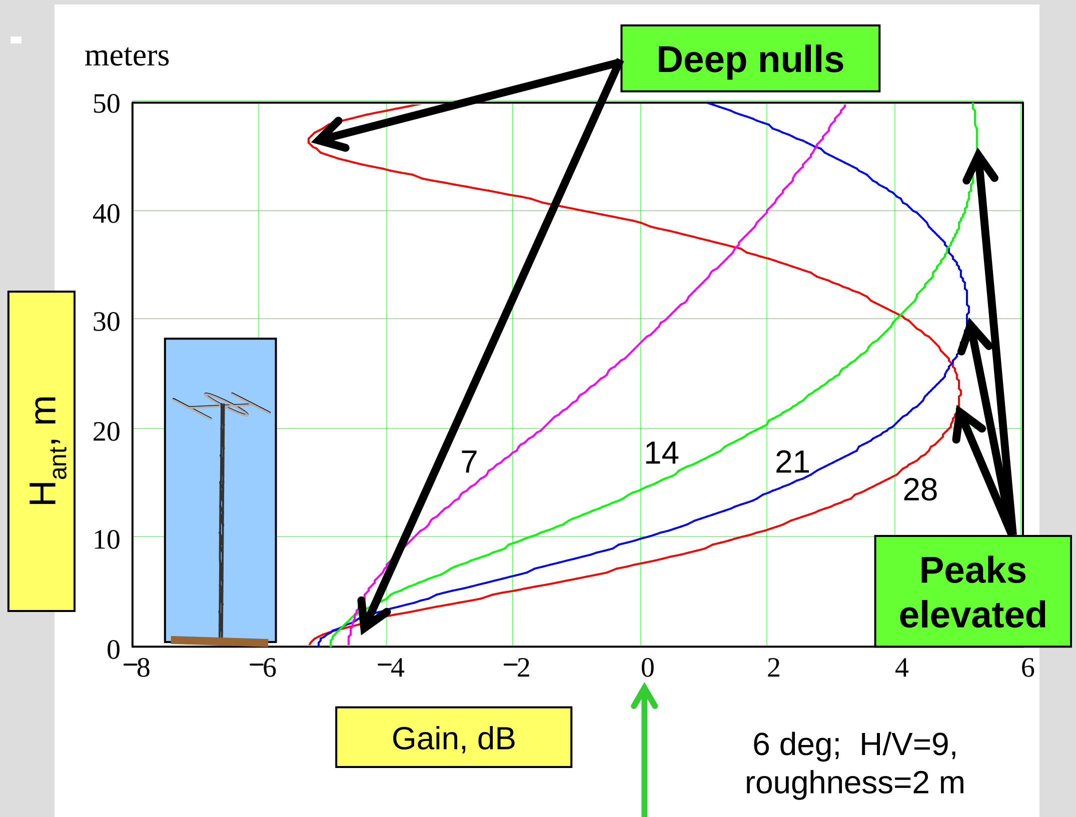
Horizontal Polarization: "The Reflection is from Land or Sea"

Horizontal polarization:
over *earth or sea water:*

There is an <u>optimum height</u> that depends on:

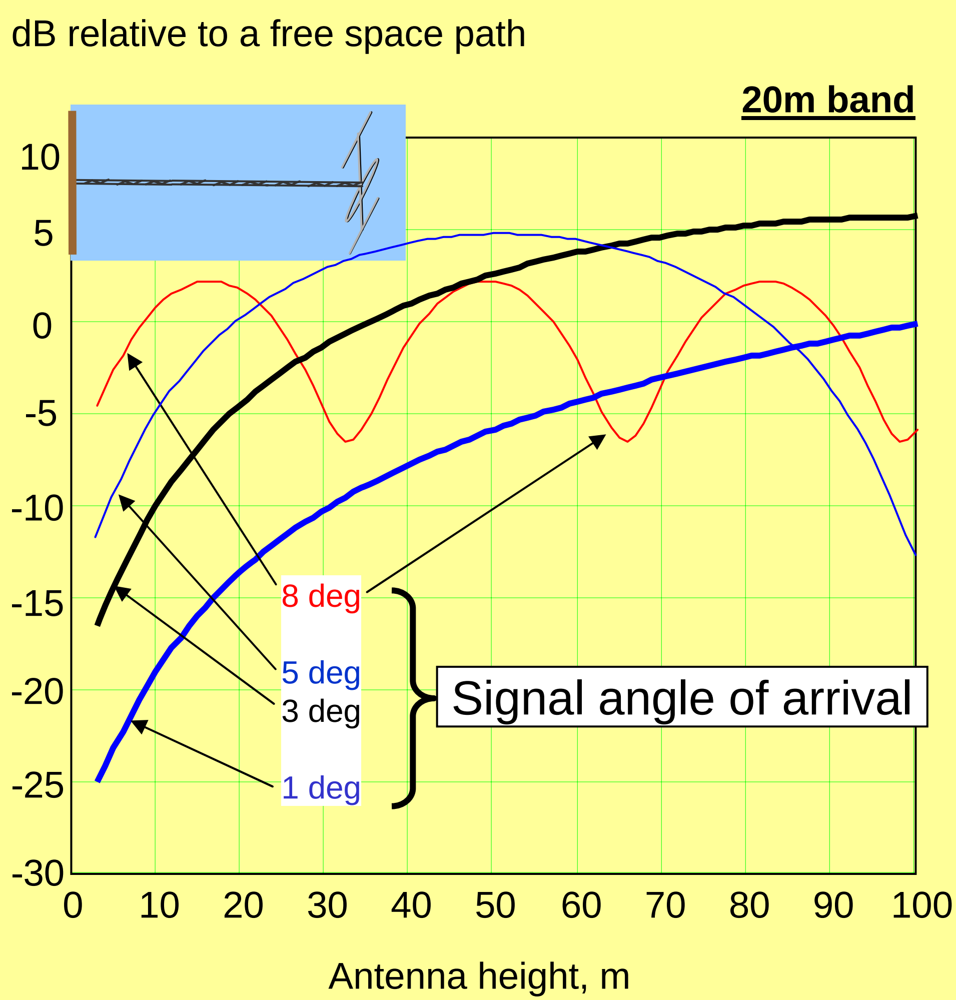
- ***frequency, and***
- ***arrival angle***

We want to place the antenna where the signal is strongest



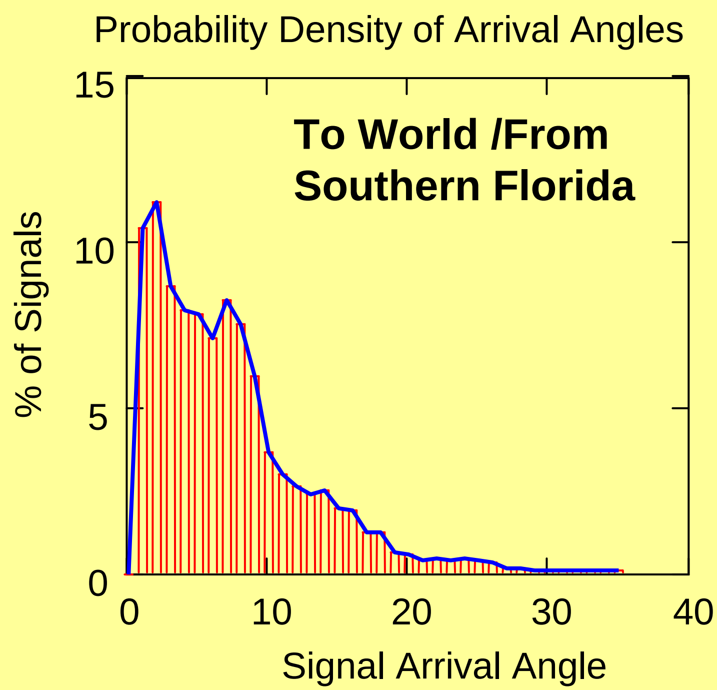
"0 dB" reference is free space (no ground reflection)

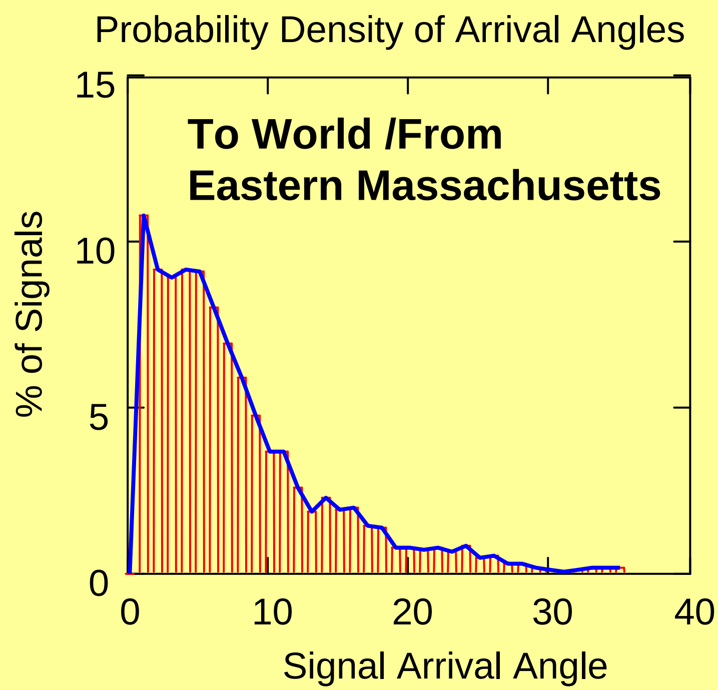
Unique Vertical Standing Waves for each Arrival Angle, Frequency



- For lowest arrival angles (1 – 5 deg), higher antenna best
- But, higher arrival angles (>5 deg) exhibit "nulls" at lower heights
- *Need to know what angles are important*

So, what arrival angles are Important?





Angles averaged over 80m – 10m to all regions of the world

50% of elevation angles < 6 deg

90% are less than 16 deg

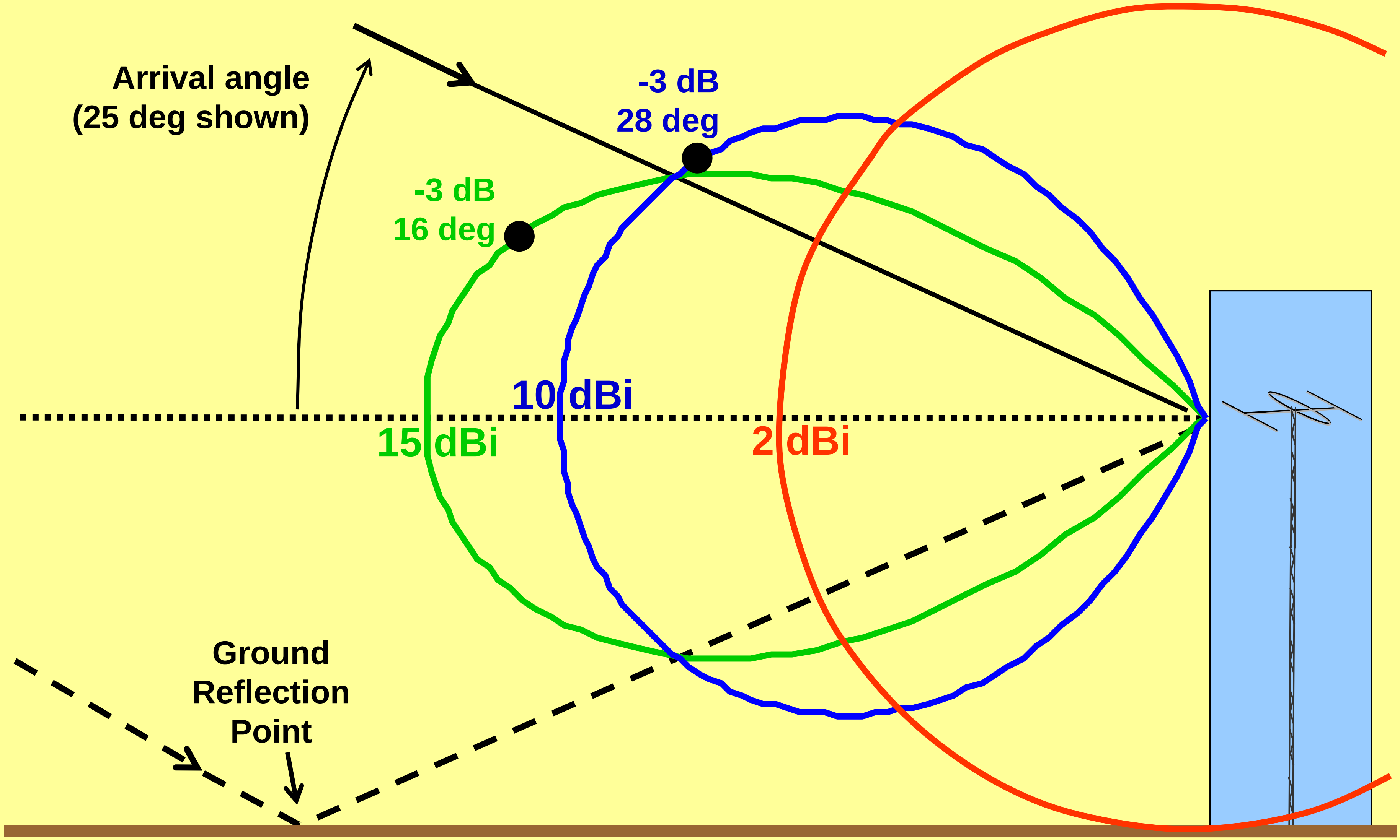
99% are less than 27 deg

1 – 7 deg most important for DX

5 – 27 deg prevalent for shorter distances (within USA)

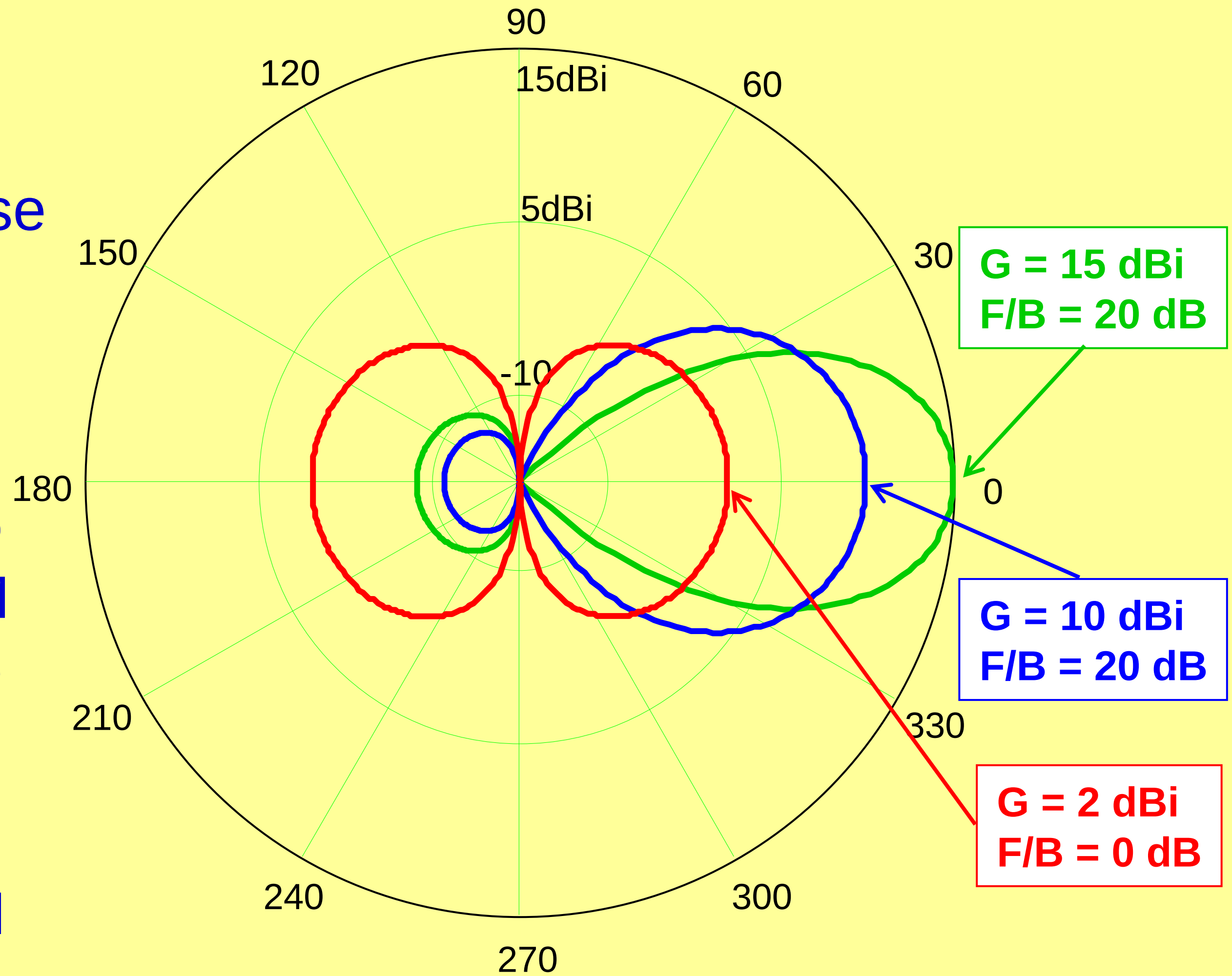
Source: http://www.arrl.org/notes/antbook/yt-files.html

Antenna Gain and Beam Width
Important to Arrival Angle



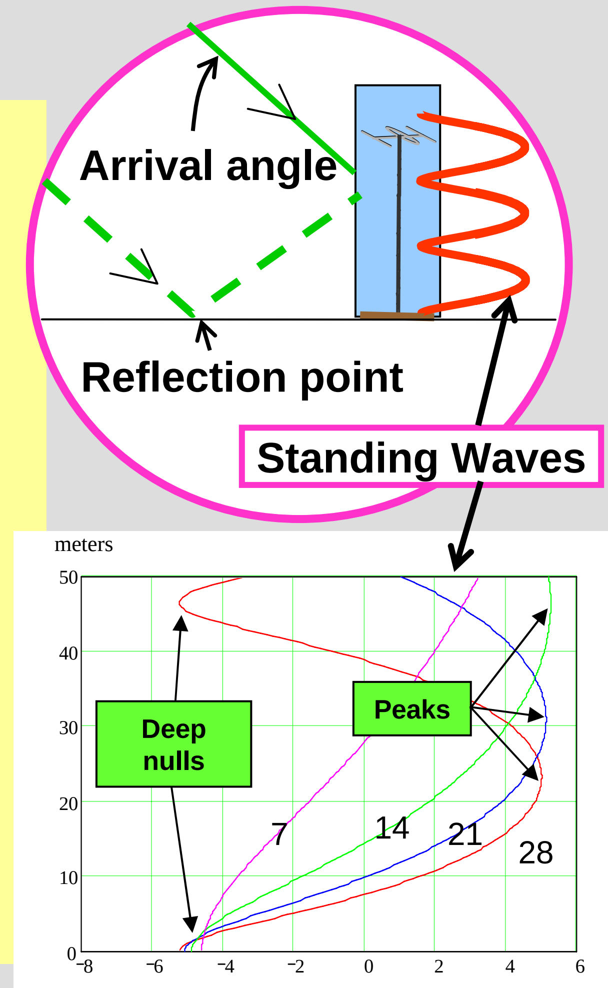
Antenna Azimuth Patterns Important for S/I

- Directivity improves desired signal, reduces off axis noise and QRM from pile-ups
- Sometimes better to place a null on QRM rather than peak the gain on the DX
- Peak the desired S/I

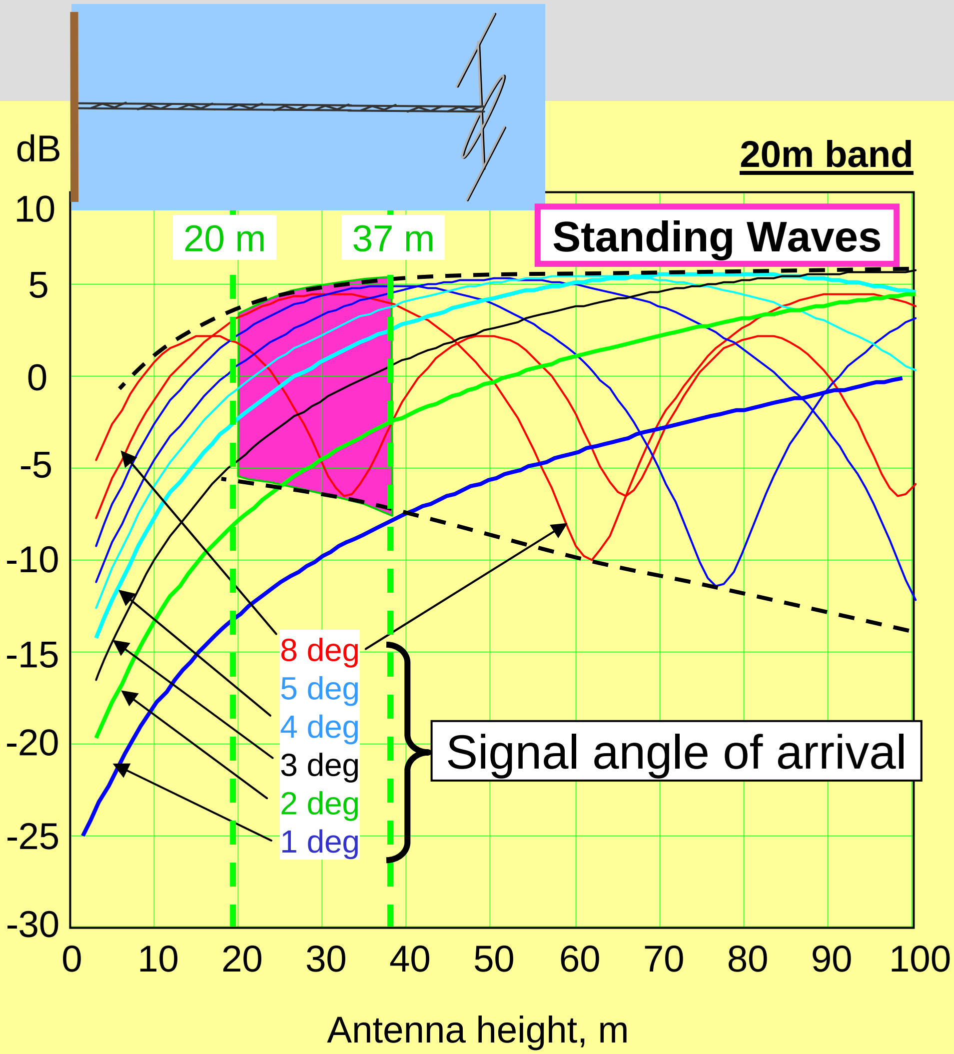


A Quick Recap …

- Direct ray + ground ray produces a vertical standing wave
- Standing wave peaks and nulls depend on frequency and arrival angle
- CONCLUSION: There is an optimum antenna height



Which Frequencies and Arrival Angles are Important for *You*?



- There is an optimum height:
  - for each band
  - for arrival angle
- Complex story, but:
  - Optimum height for HF is around 55 – 95 ft
  - Lower antennas less effective for lowest angles
  - Higher antennas less effective for medium and higher angles

How Can We Measure Antenna System Performance?

CQ-DX-Marathon provides a uniform measure of achievement

Rules: Work as many DX entities as possible in one year, Jan 1 – Dec 31

Everyone has the same goal and same time frame

Two classes, so we can track performance based on antennas and power

Unlimited Class: Any antenna, any legal power level

Formula Class Option 1:

10 watts, antennas on single tower, height under 65 feet

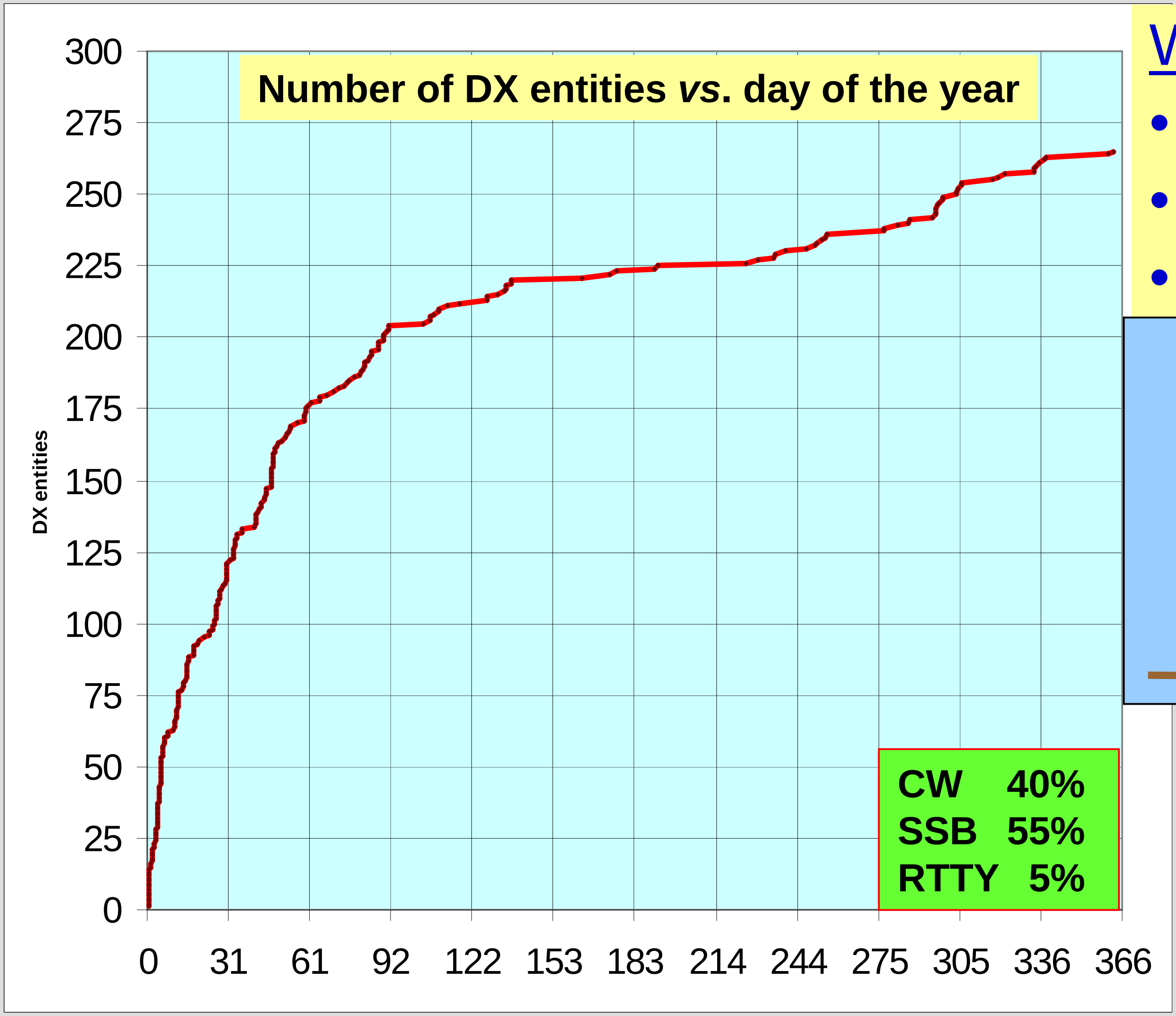
Formula Class Option 2:

100 watts with either simple verticals less than 33 ft above ground, or wire antennas less than 60 ft above ground and lacking significant gain; no arrays, yagis, or quads

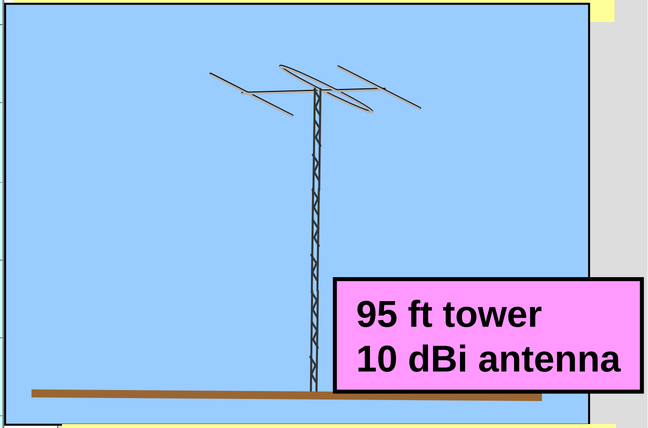
CQ Magazine also sponsors the WPX and WAZ Awards

Source: http://dxmarathon.com/Contestrules/index.htm

If you Use a Top of the Line Station, and Use it Well ...



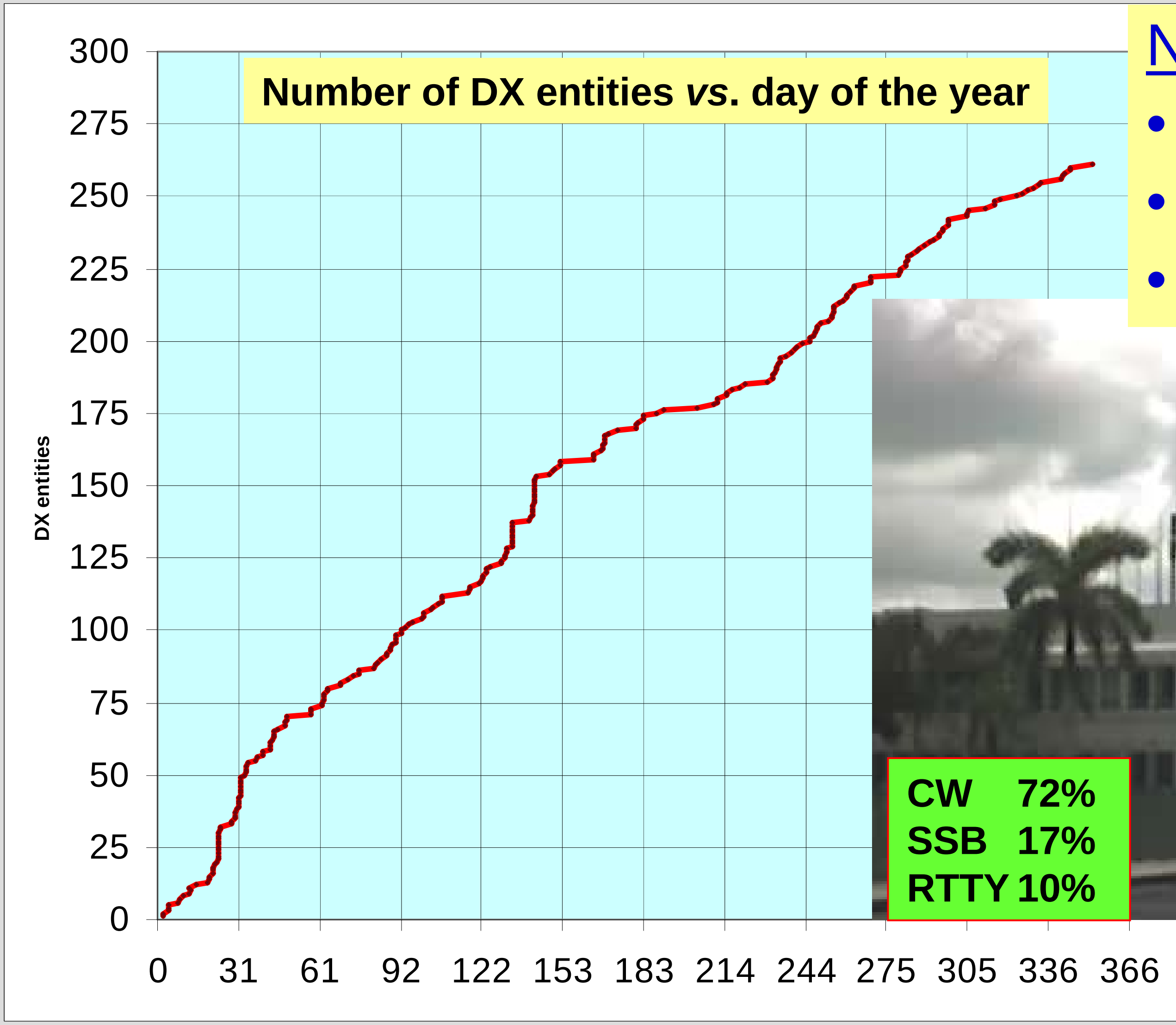
W4QN
- 95 ft tower
- 10dBi antenna
- kilowatt

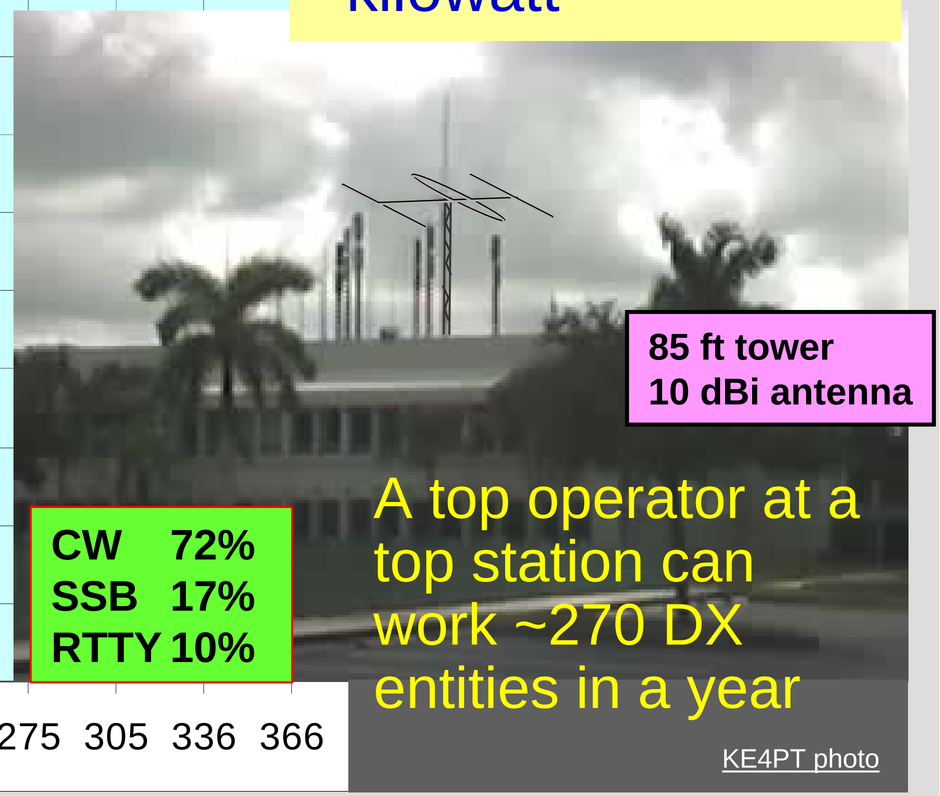


A top operator at a top station can work ~270 DX entities in a year

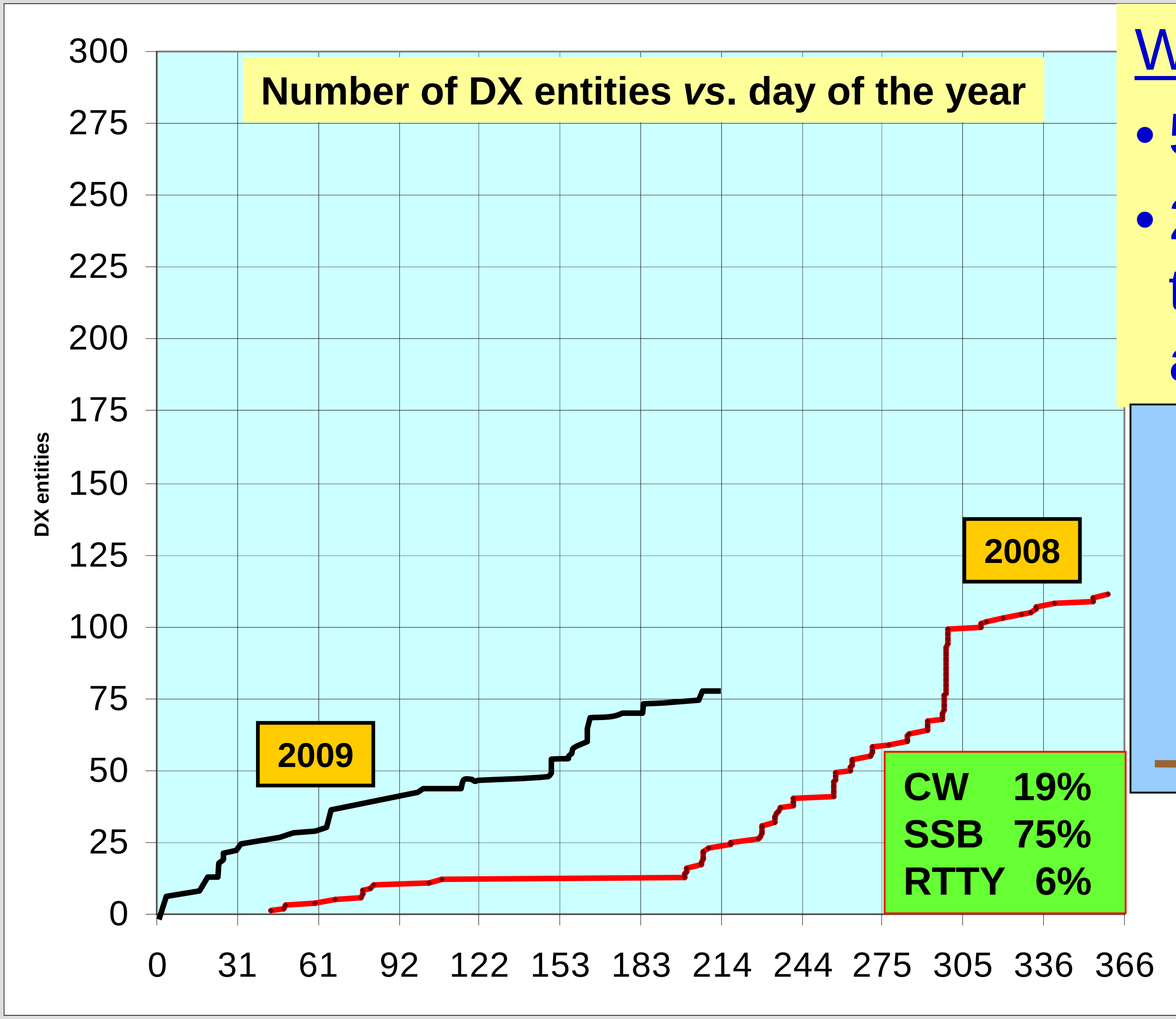
If you Use a Top of the Line Station, and Use it Well ...

N4II at W4MOT
- 85 ft tower
- 10 dBi antenna
- kilowatt



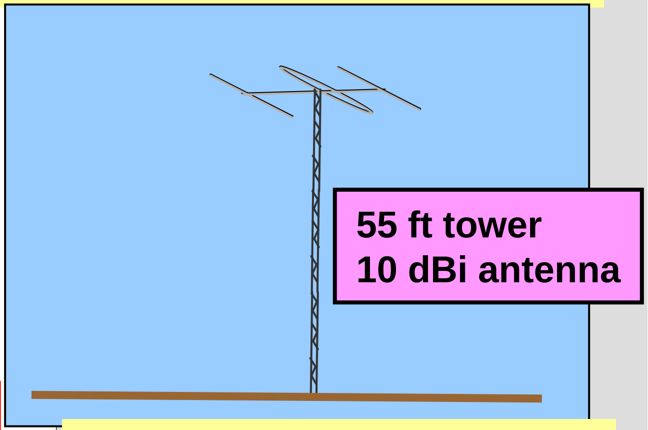


With a Moderate Height Station, and Favoring Voice



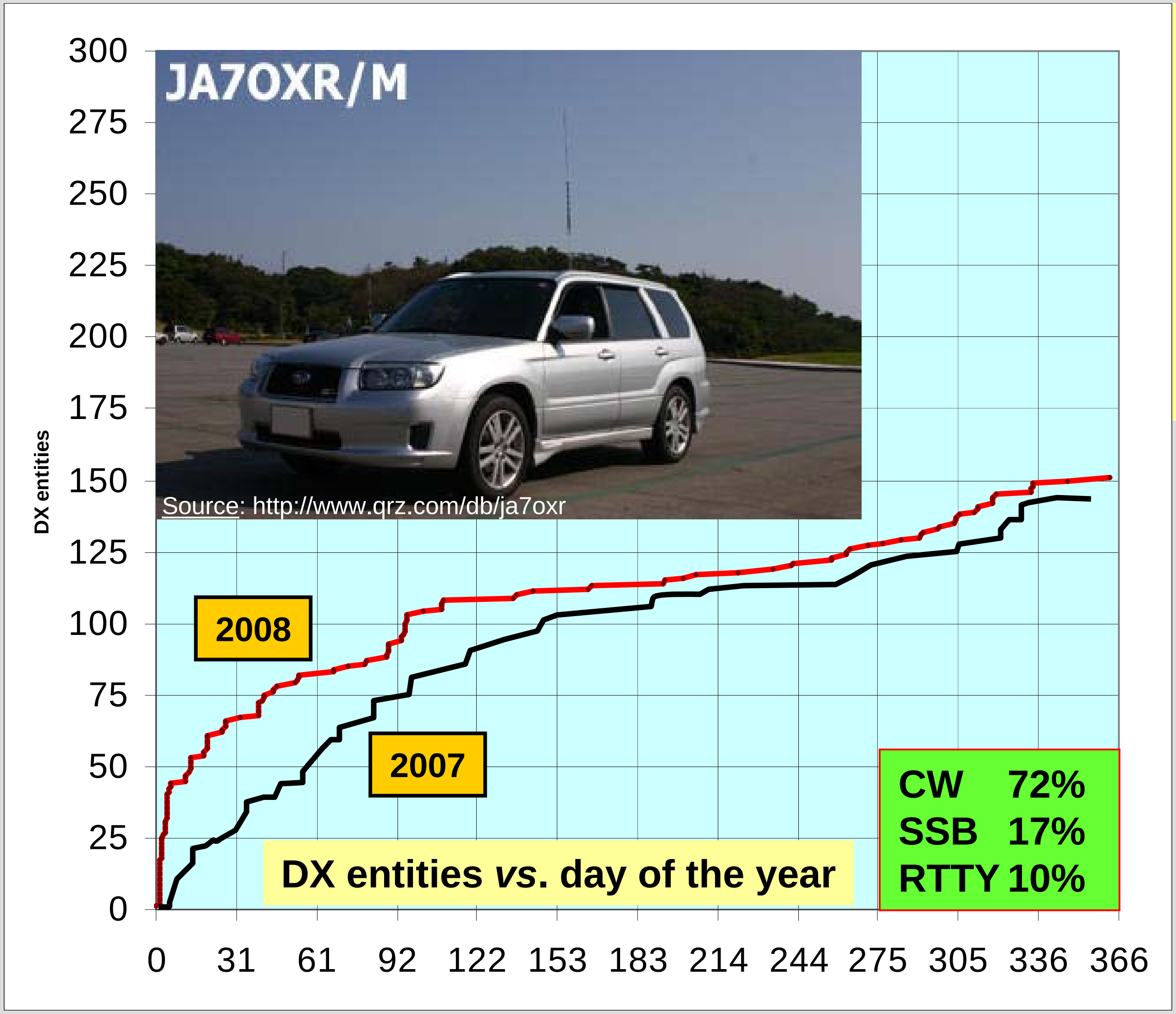
W4DTA

- 55 ft tower
- 2 element quad then SteppIR antenna



Typical station can work over 100 DX entities in a year

Mobile Station, Low Power but Favoring CW



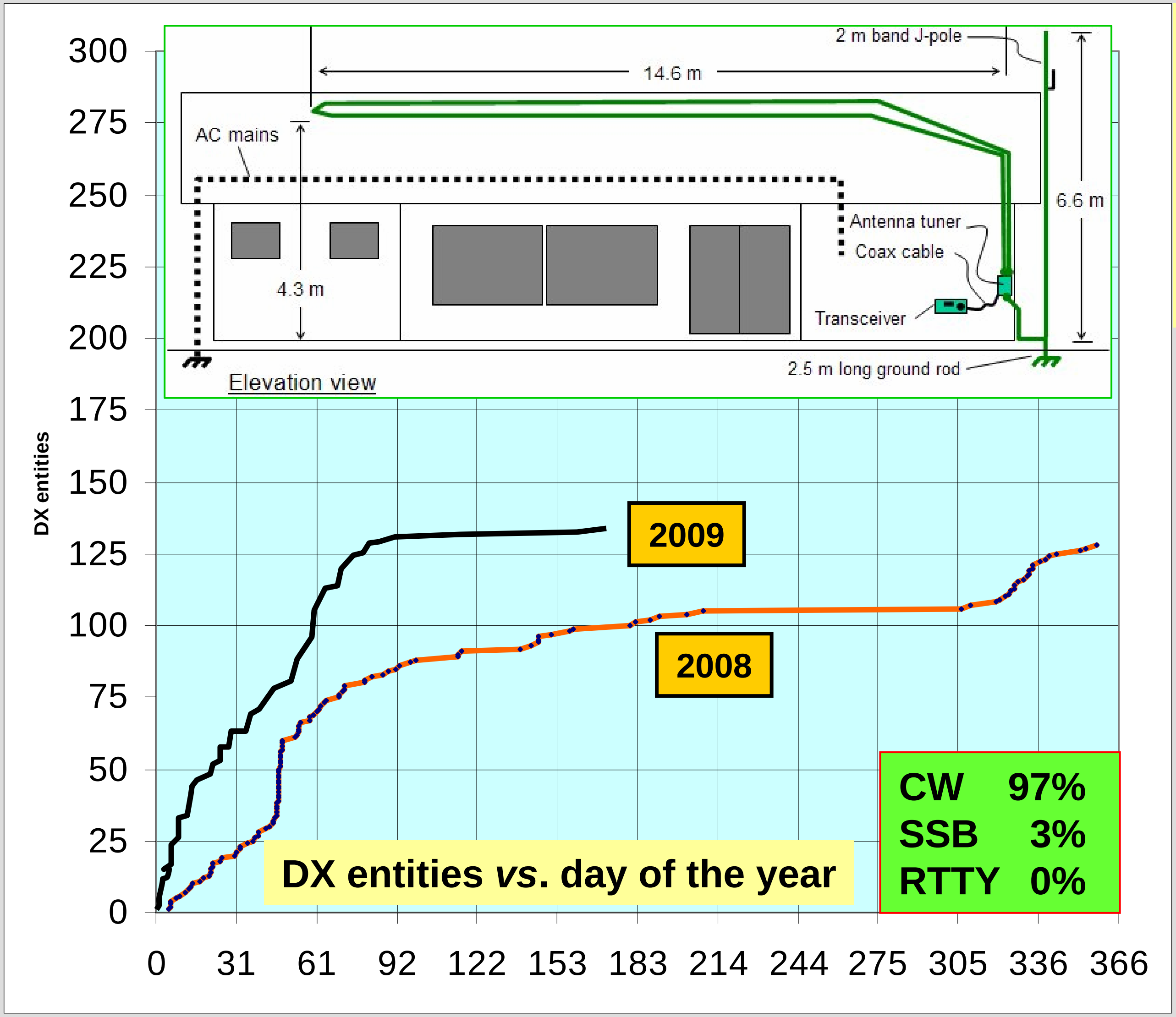
JA7OXR

- All mobile effort
- 50 watts
- can pick a quiet location

Vertical mobile antenna

A mobile station can work ~150 DX entities in a year

Indoor Antenna Station, Mostly CW



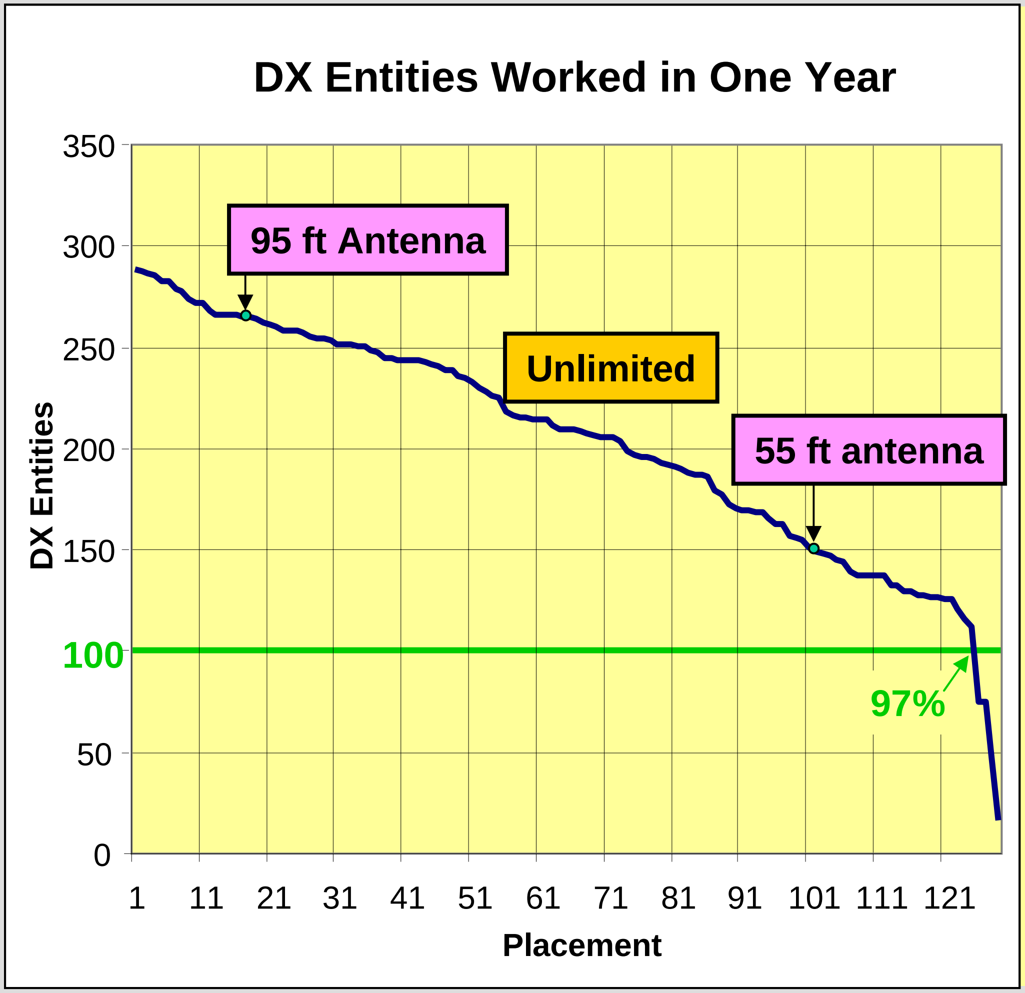
KE4PT

- Indoor antenna
- ~0 dBi
- 100 watts

Indoor antenna

Modest station with "no visible means of antenna" can work ~130 DX entities in a year

Summary: CQ-DX Marathon 2008



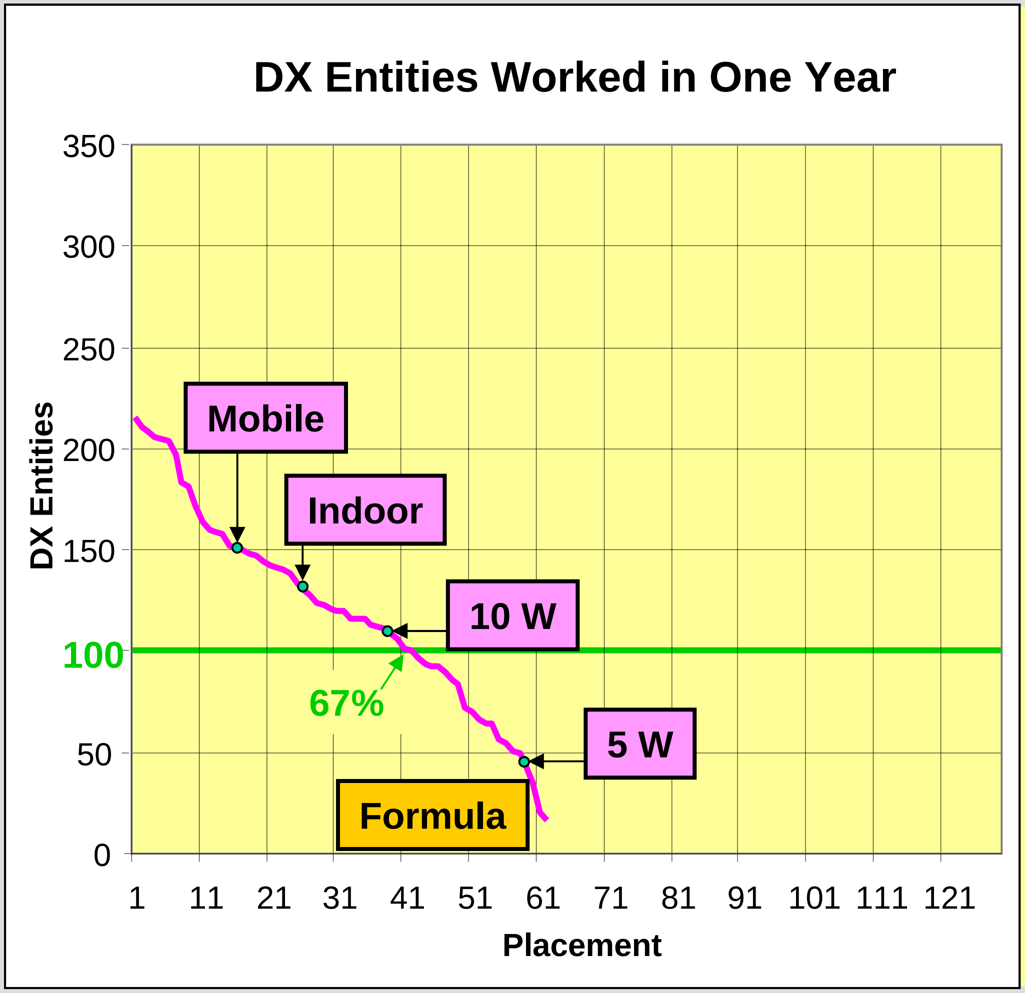
In one calendar year, even with few sun spots ...

Unlimited Class stations can work almost 300 DX entities in a year: up to 30 dB advantage over modest station:

- 10 dB in height gain
- 10 dB in antenna gain
- 10 dB in power

97% of "Unlimited Stations" worked more than 100 DX entities in one year, CAN USE ANY MODE

Summary: CQ-DX Marathon 2008



In one calendar year, even with few sun spots ...

67% of "Modest Stations" worked more than 100 DX entities in one year:
BEST RESULTS with CW

Modest stations 100 watts or less and with no significant antenna gain can work over 200 DX entities in a year

QRP station (<10 watts) can aspire to 100 DX entities!

Not Really an Antenna Issue, but ... CW/digital vs. SSB

With 100 watt PEP transmitter, CW average power is 44 watts, with SSB it is only 22 watts

- 3 dB advantage for CW

A receiver CW filter noise BW is 350 Hz compared with 2,700 Hz for SSB

- 9 dB advantage for CW

CW operators, especially experienced DX operators, listen more intently to CW

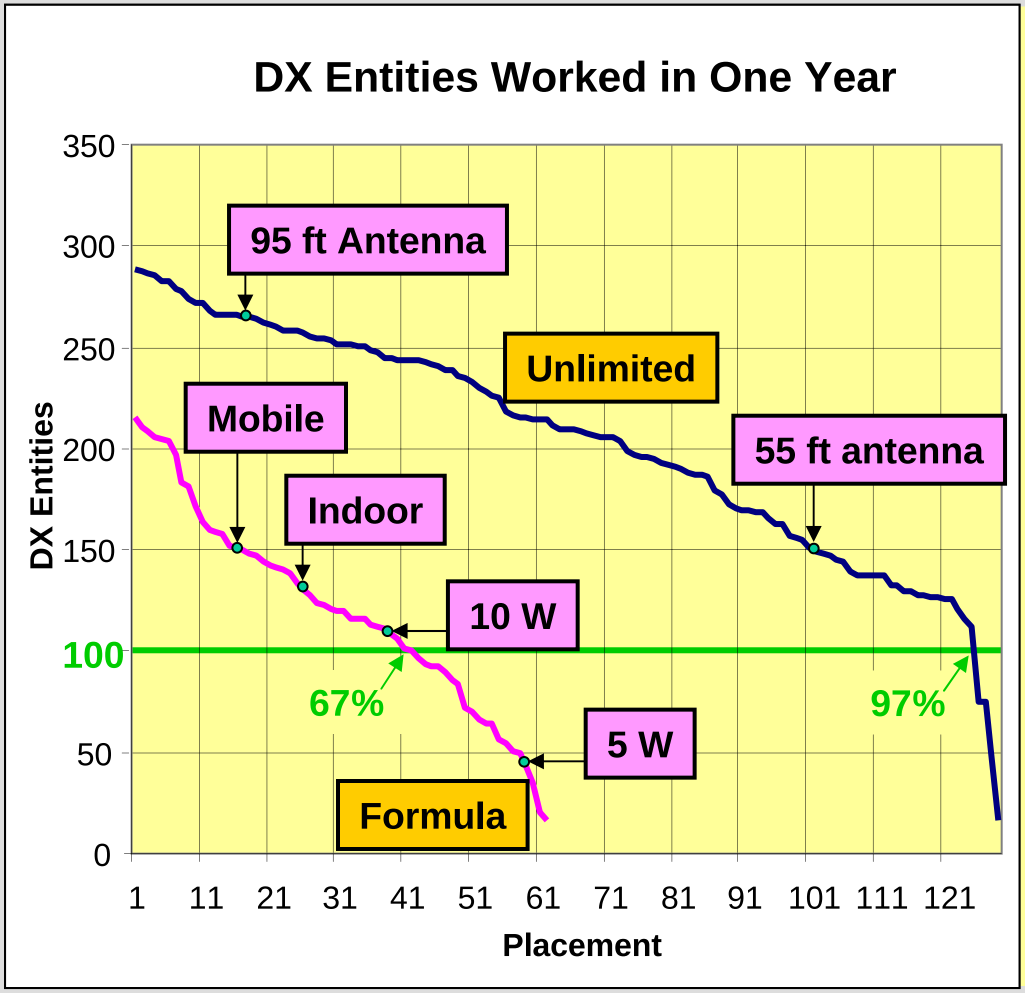
- 4 dB advantage for CW

There is a net CW advantage equivalent to 3 S-units!

- Total: 16 dB advantage for CW over SSB

Similar advantage can be claimed for the narrow band digital modes

Summary: CQ-DX Marathon 2008



In one calendar year, even with few sun spots ...

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QRP station (<10 watts) can aspire to 100 DX entities!

Antennas: the "take away"

- **DXCC possible using 10 – 100 watts and simple antennas within one year** (67% probability)

- No Surprise: the probability increases to 97% for Yagis on optimum height towers, kilowatt, good operator: *flexible with operating modes*
- Optimum antenna height is 55 – 95 feet for Horizontal Polarization
- Surprise: Mobiles, Verticals, Indoor Antennas can yield very good results: *favor CW/Digital modes*

What About RF Safety?

Certify your Station

Several ways to go ...

- **Tables and charts (Easy to use)**
- **Calculations (Simple calculator best)**
- **Measurements (Rarely a good idea)**

“READ CAREFULLY BEFORE SIGNING”

When you obtain or renew your ham license you use FCC form 605.

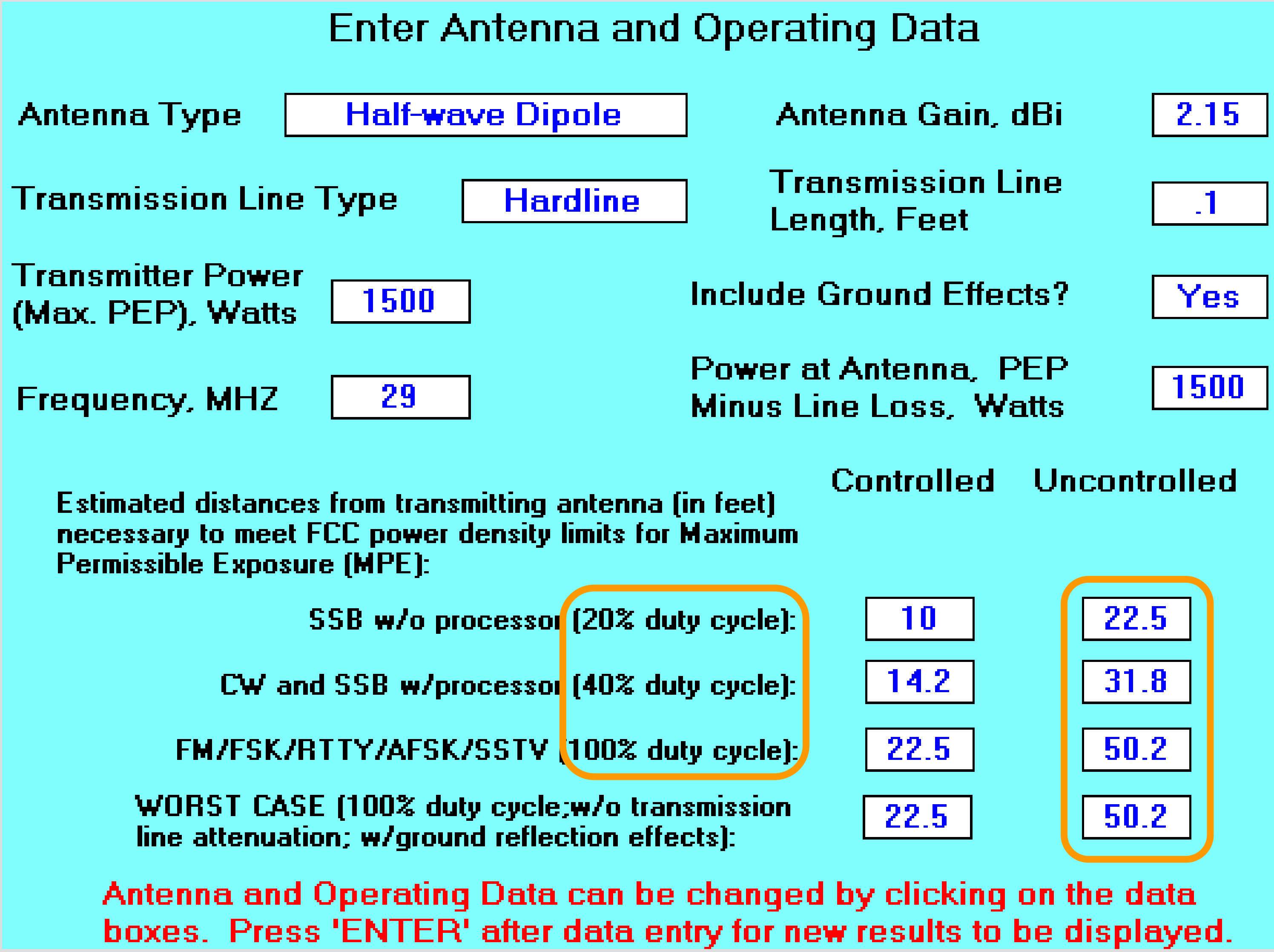
By signing the form you agree to the following *fine-print text:*

“I *certify* that: … I have read and WILL COMPLY with Section 97.13(c) of the Commission’s Rules regarding RADIOFREQUENCY (RF) RADIATION SAFETY and the amateur service section of OST/OET Bulletin Number 65.”

Without Exception: *All* Stations Must Be CERTIFIED

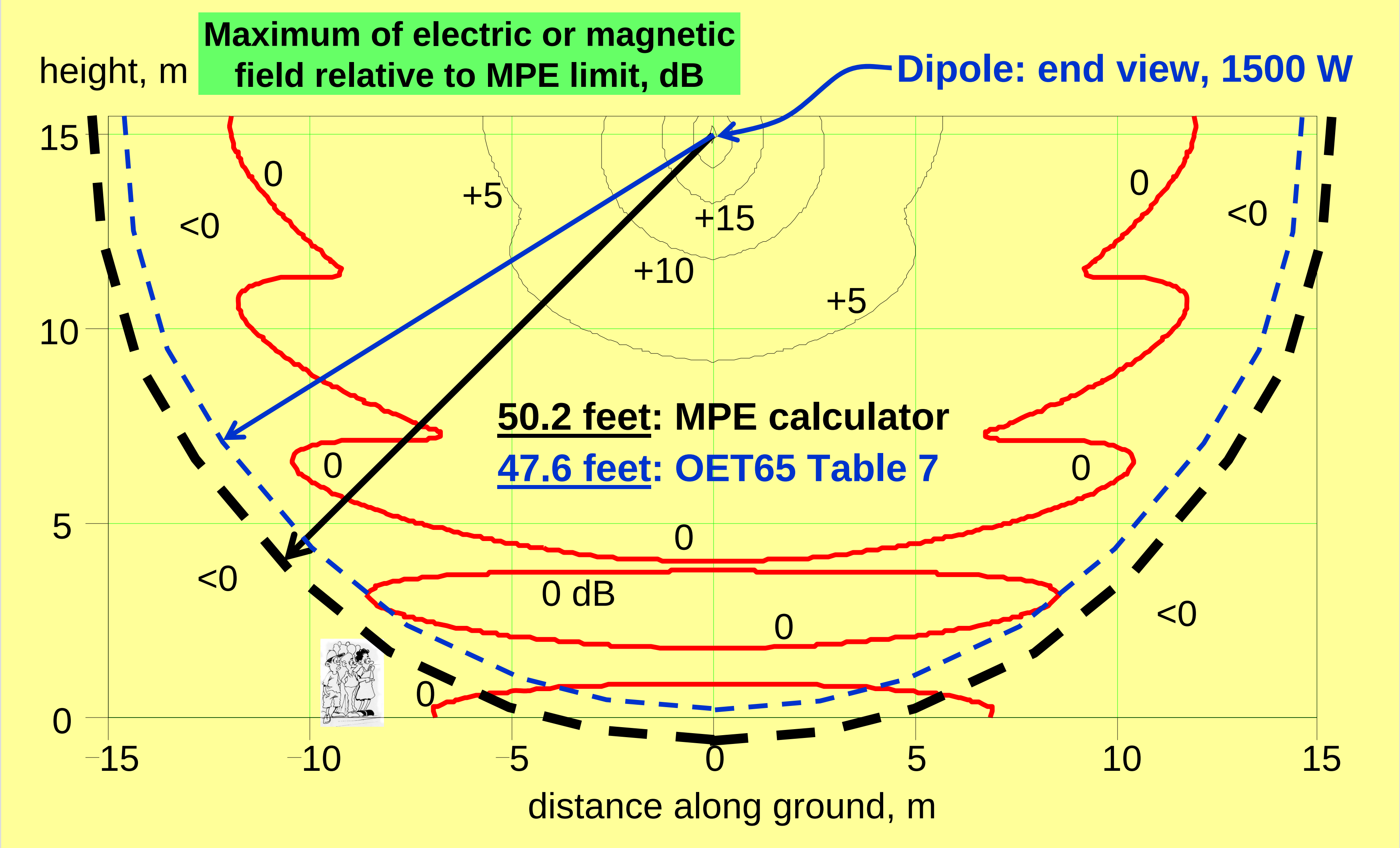
- Basis of RF exposure standards in the regulations
  - § 97.13(c) starts the process for Hams
  - § 1.1310 “Radiofrequency radiation exposure limits”
  - § 2.1093 “Radiofrequency radiation exposure evaluation: portable devices” (20 cm separation)
- Some stations are exempted from *evaluation*

Easiest: (Free) MPE Calculator



Source: http://www.qsl.net/w0jec/index.html

Actual Fields are "Messy", MPE Calculator and OET65 Tables are Easy to Use!



Source: RF Exposure and You, ARRL, 1995

Certify Your Station!

For most cases:

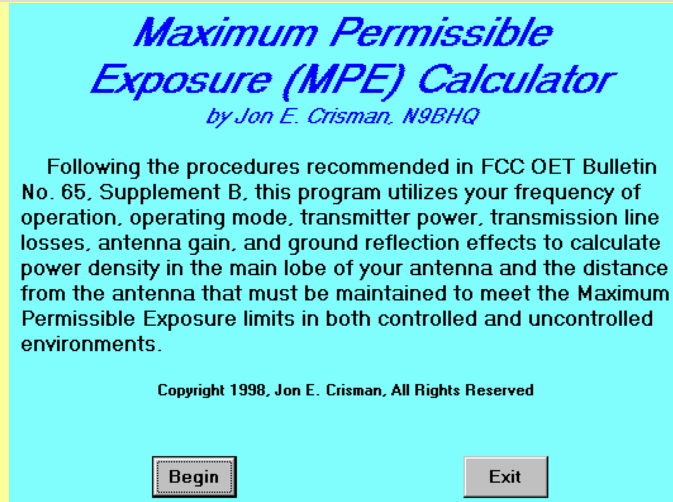
- Use MPE calculators
- Use FCC OET Bulletin 65
- Avoid meters!

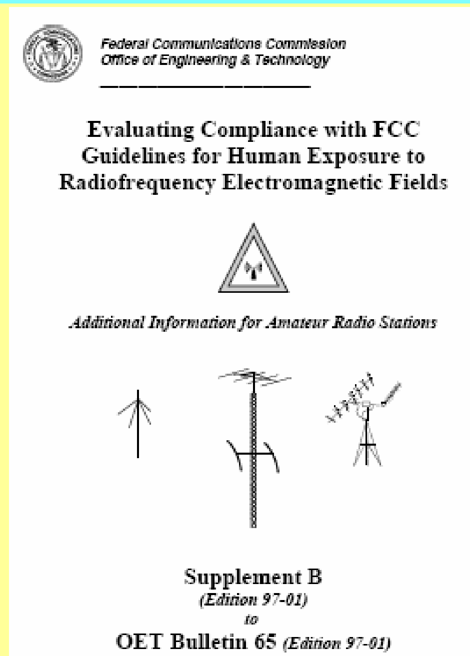
For stubborn cases:

- Use calculations from NEC

Help available:

- ARRL RF Safety Committee
- ARRL Technical Advisors




Federal Communications Commission
Office of Engineering & Technology

Evaluating Compliance with FCC Guidelines for Human Exposure to Radiofrequency Electromagnetic Fields

Additional Information for Amateur Radio Stations

Supplement B
(Edition 97-01)
to
OET Bulletin 65 *(Edition 97-01)*

Source: http://www.narda-sts.us/

Antenna Modeling

What the equations mean ...

$$\nabla\times\mathbf{H} = \frac{\partial\mathbf{D}}{\partial t} + \mathbf{J} \qquad \nabla\times\mathbf{E} = -\frac{\partial\mathbf{B}}{\partial t}$$

H and E fields wrap (curl) around each other ...

$$\mathbf{B} = \mu_0\mathbf{H} \qquad \mathbf{D} = \varepsilon_0\mathbf{E}$$

$$\nabla\bullet\mathbf{J} = -\frac{\partial\rho}{\partial t} \qquad \nabla\bullet\mathbf{D} = \rho \qquad \nabla\bullet\mathbf{B} = 0$$

subject to physical constants, and sources ...

$$\mathbf{B} = \nabla \times \mathbf{A} \qquad \mathbf{E} = -\nabla\Phi - j\omega\mathbf{A}$$

$$\nabla^2\mathbf{A} + k^2\mathbf{A} = -\mu\mathbf{J} + \nabla(\nabla\bullet\mathbf{A} + j\omega\mu\varepsilon\Phi)$$

and after much mathe*magical* manipulation ...

$$\mathbf{A} = \frac{\mu_0}{4\pi} I\Delta l \frac{e^{-jkr}}{r}\,\mathbf{z}$$

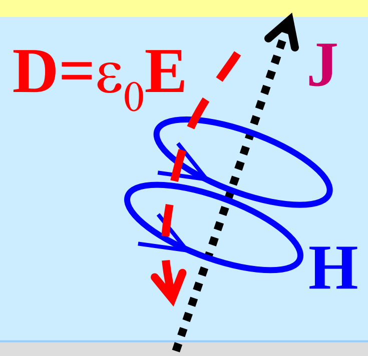
... currents radiate!

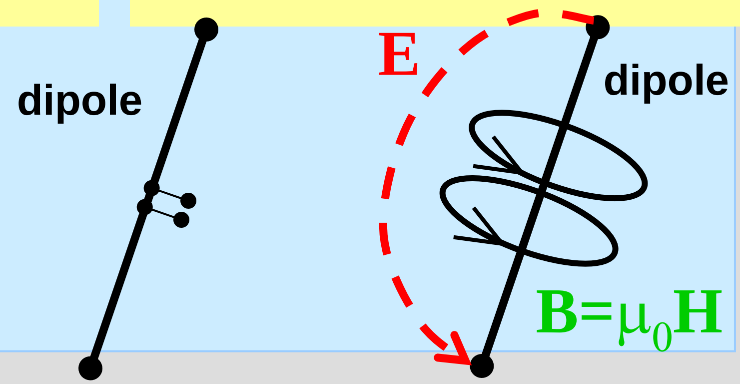
What the equations mean …

$$\nabla \times \mathbf{H} = \frac{\partial \mathbf{D}}{\partial t} + \mathbf{J} \qquad \nabla \times \mathbf{E} = -\frac{\partial \mathbf{B}}{\partial t}$$

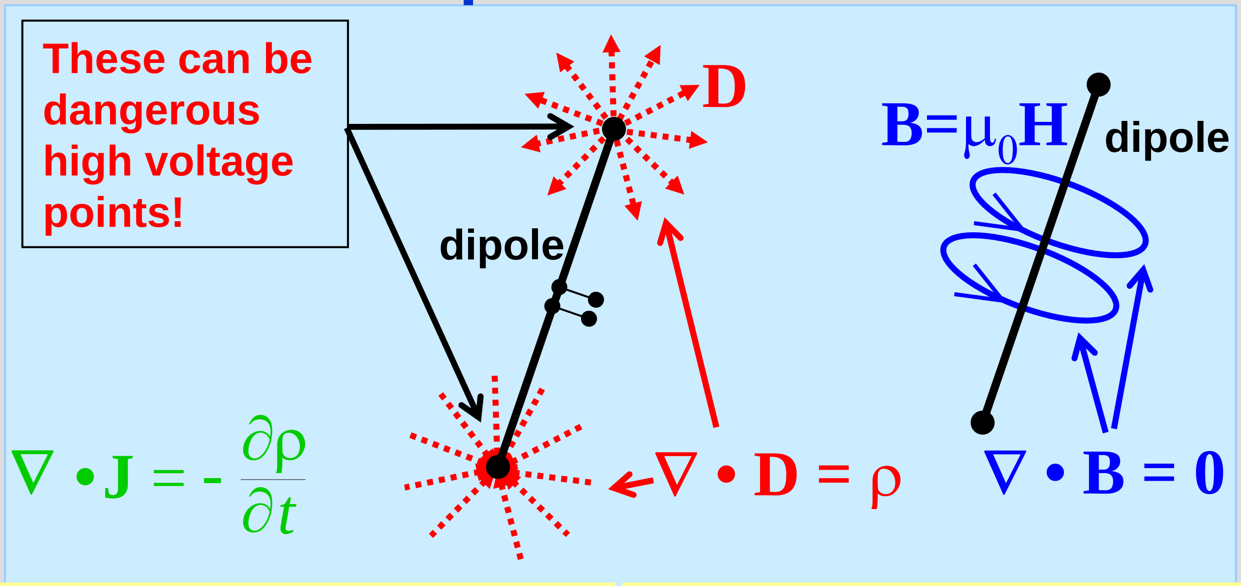
- A magnetic field **H** will ‘curl’ around a time-varying electric displacement **D**, and around a surface current **J**

- An electric field **E** will ‘curl’ around a time varying magnetic flux **B**





What the equations mean …



- Diverging current densities **J** are related to moving charge densities ρ

- Electric displacement field **D** originates at charge densities ρ
- Magnetic flux lines don't terminate at points or surfaces

What the equations mean ...

- Finally, we can perform lots of complex vector math to write a "wave equation"

- Solve the wave equation to give an expanding wave front e^{-jkr}/r due to the antenna current I

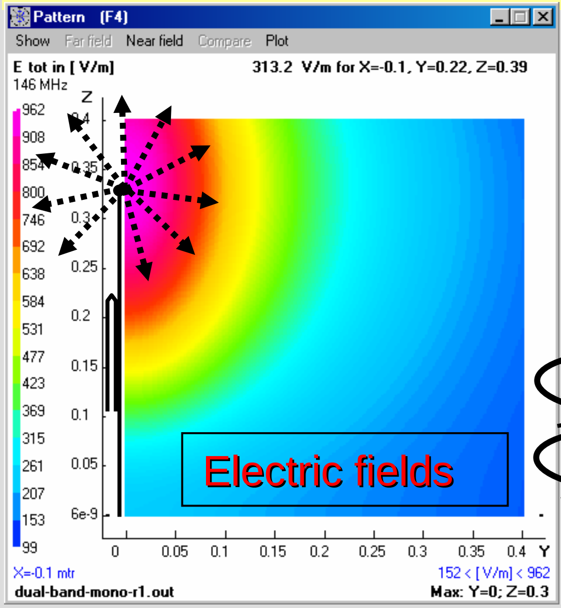
$$\mathbf{B} = \nabla \times \mathbf{A} \qquad \mathbf{E} = -\nabla\Phi - j\omega\mathbf{A}$$

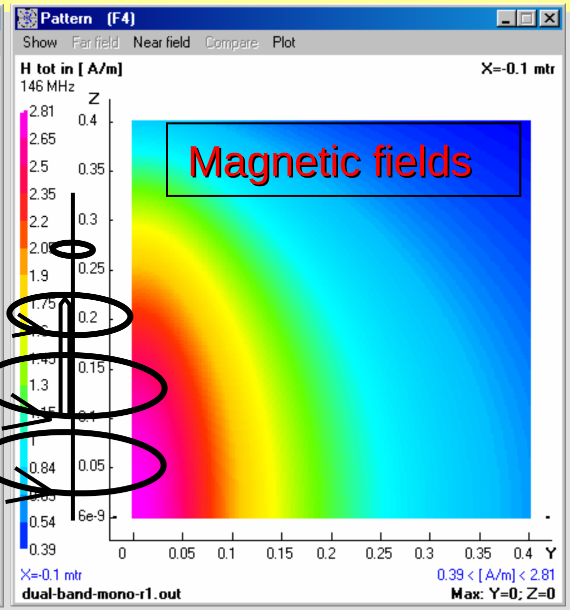
$$\nabla^2\mathbf{A} + k^2\mathbf{A} = -\mu\mathbf{J} + \nabla(\nabla\bullet\mathbf{A} + j\omega\mu\varepsilon\Phi)$$

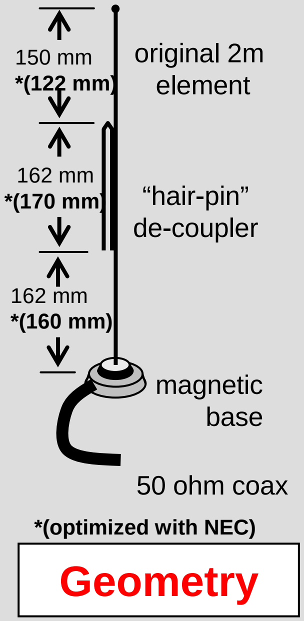
$$\mathbf{A} = \frac{\mu_0}{4\pi} I\Delta l \frac{e^{-jkr}}{r} \mathbf{z}$$

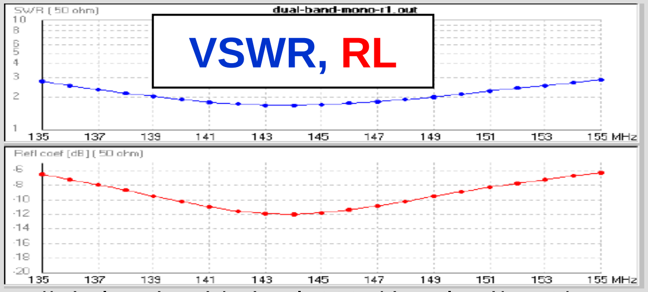
How we use the equations …

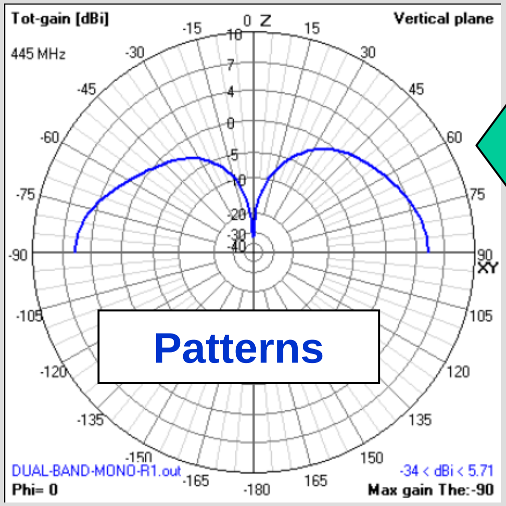
- Hams "solve" these equations inside applications like "4nec2", EZNEC, "MiniNEC","NEC-2,3,4", "NEC-WinPro"...





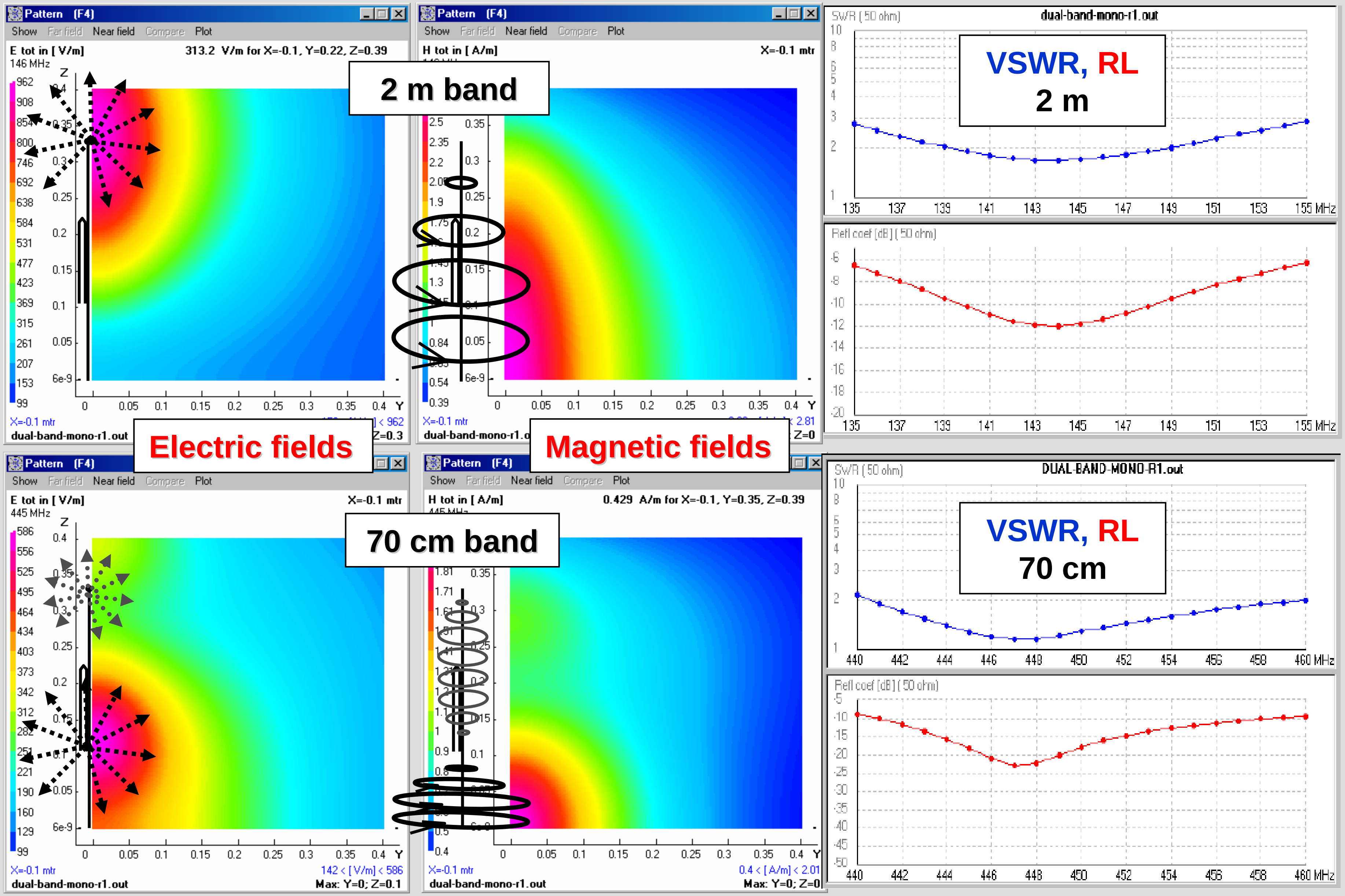






Source: 4nec2 by Arie Voors: http://wireless.ictp.it/school_2005/download/nec2/

The Antenna in Two Bands …



QUESTIONS?

- **Signals from the Ionosphere**
- **Antennas**
- **Towers**
- **RF Safety**
- **Antenna Theory**