DX University: Antennas

***2009 August 31** [updated 2 Sept 2012]*

Kai Siwiak, KE4PT

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

No Antenna Theory, Just Results

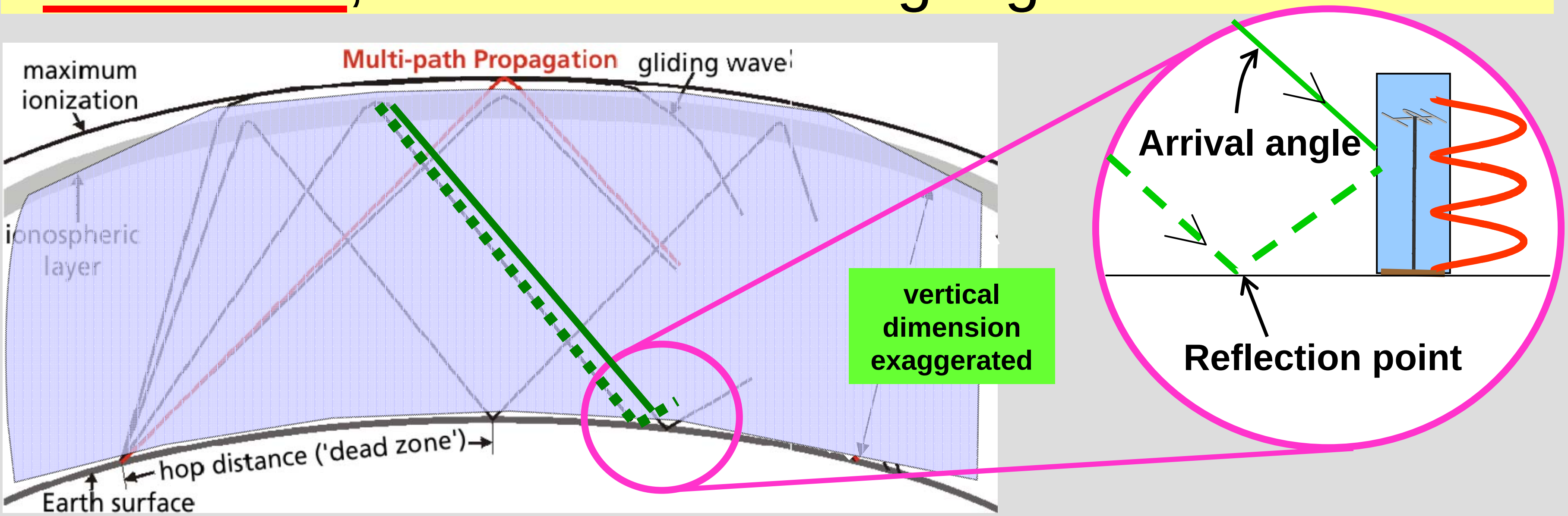
- **What does it take to work DX?**
  - **Where you place the antenna matters because signals vary with height**

- **We want to know how well different ham antenna systems perform**
  - **Yagis / Quads on Towers**
  - **Mobiles and Verticals**
  - **Indoor Antennas and Simple Wire Antennas**

"... lots of birdies on your signal, OM ..."

Why Signal Strength Varies with Antenna Height

- Ground reflections cause vertical **STANDING WAVE PATTERN**, or variation in "height gain"

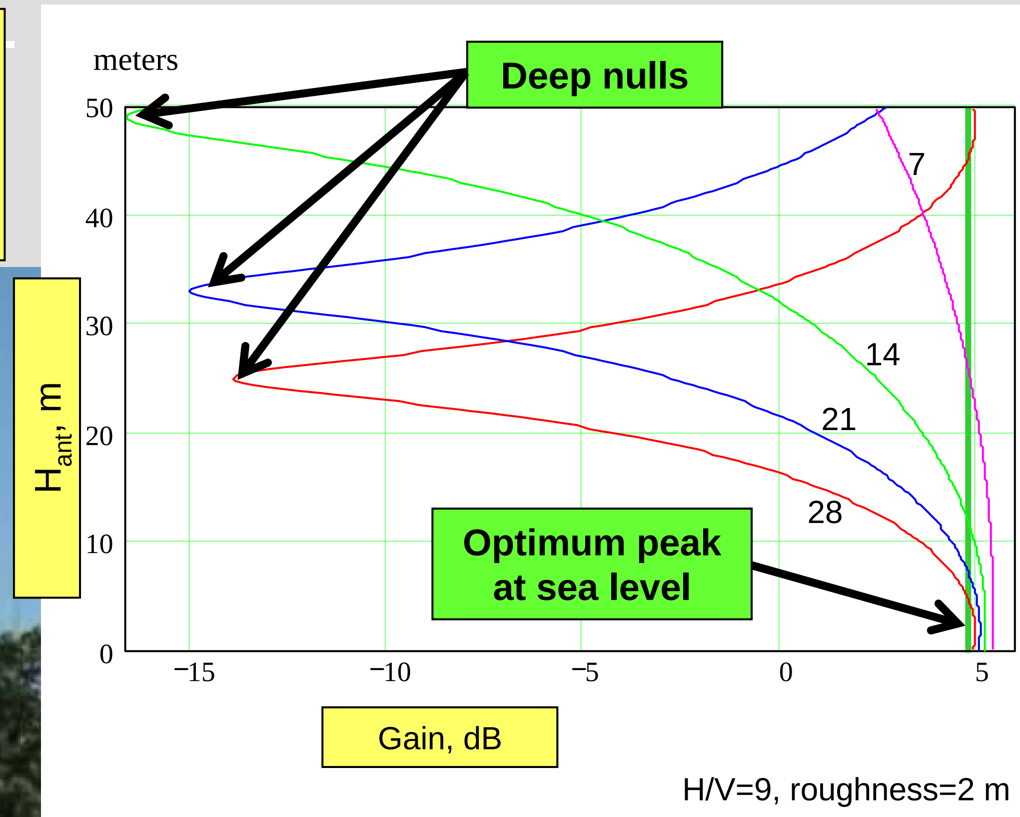


- Vertical Standing Wave means there is an Optimum Height for Antennas

Stay tuned: Propagation will be covered in Session #5

<u>Vertical Polarization</u>: "The Reflection Point is Sea Water"

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



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

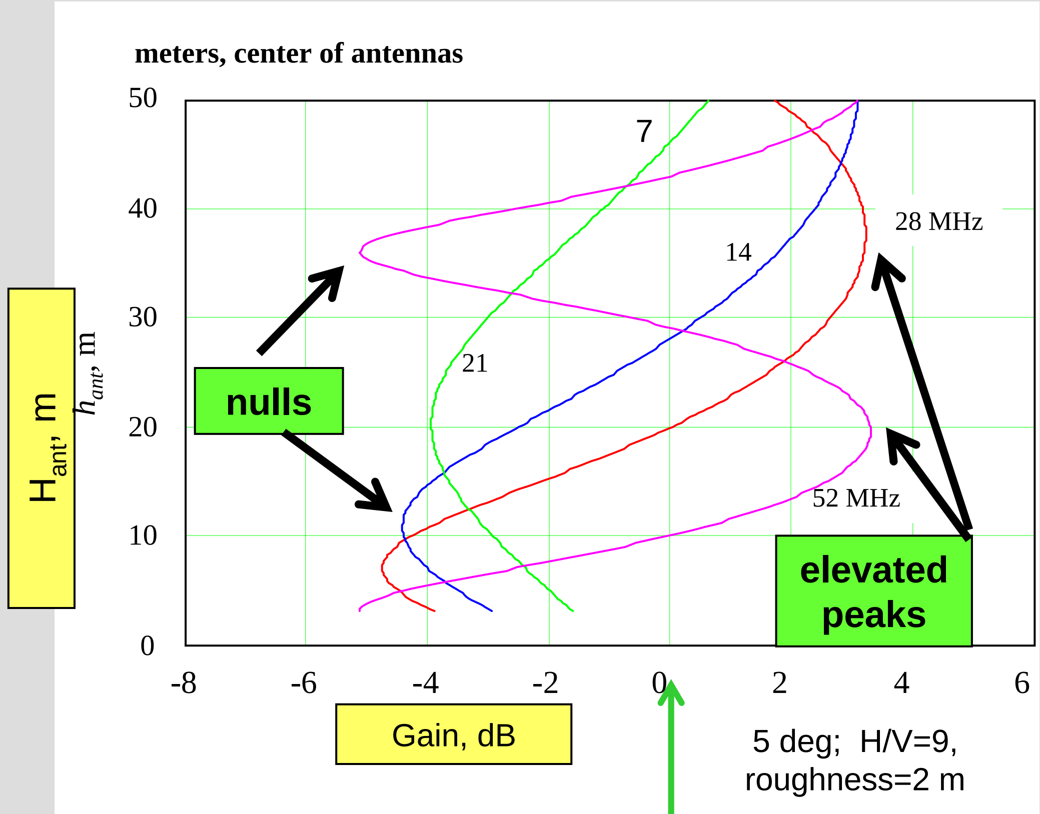
<u>Source</u>: VP6DX Ducie Antennas: http://www.youtube.com/watch?v=rwtZBtHJTew

Vertical Polarization:
"The Elevated Vertical Antenna"

Vertical polarization (elevated vertical dipole) over *earth:*

Optimum height is elevated; depends on
- ***frequency, and***
- ***arrival angle***

Behaves somewhat like horizontal polarization



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

New page: 14 June 2010

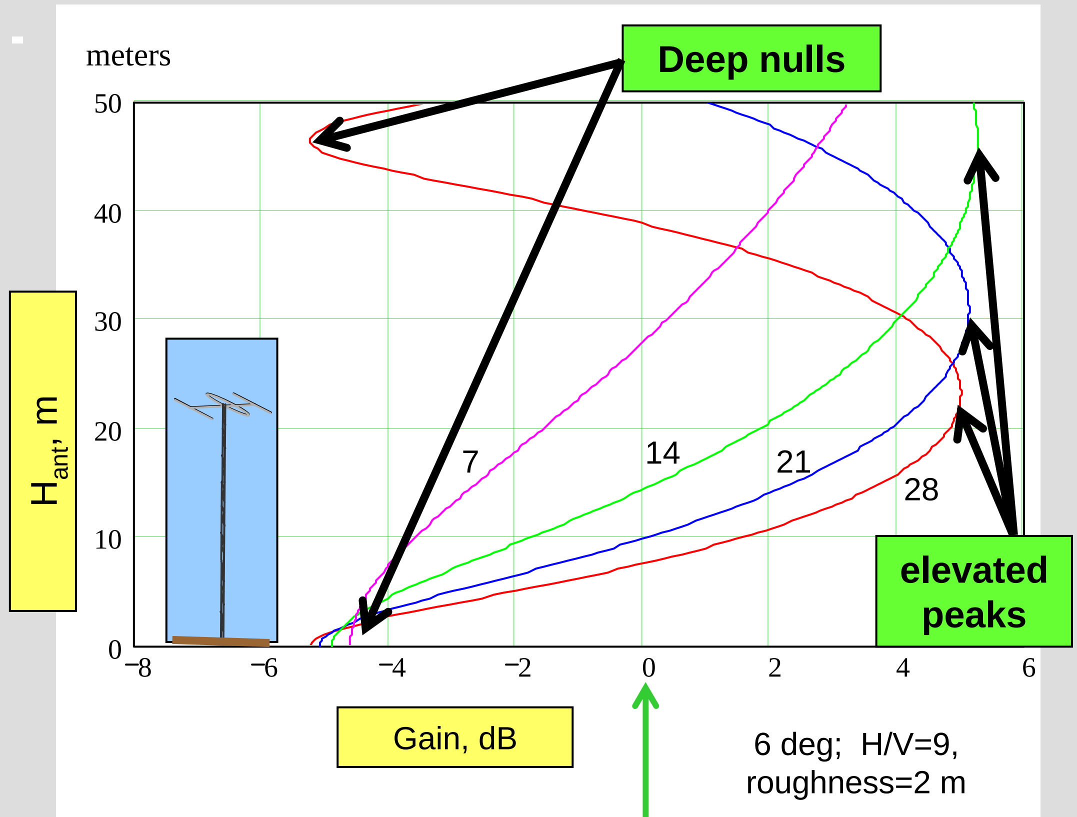
Horizontal Polarization: "The Reflection is from Land or Sea"

Horizontal polarization:
over *earth or sea water:*

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

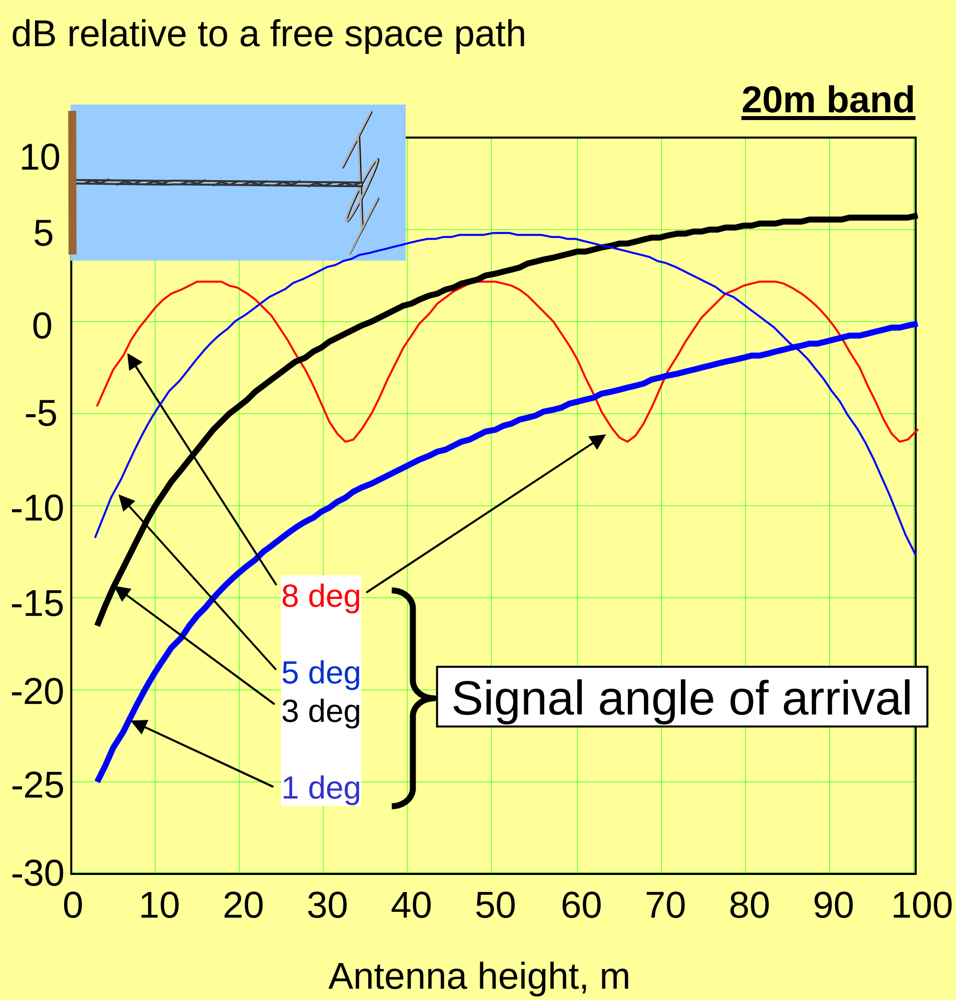
- ***frequency, and***
- ***arrival angle***

We want to place the antenna where the signal is strongest



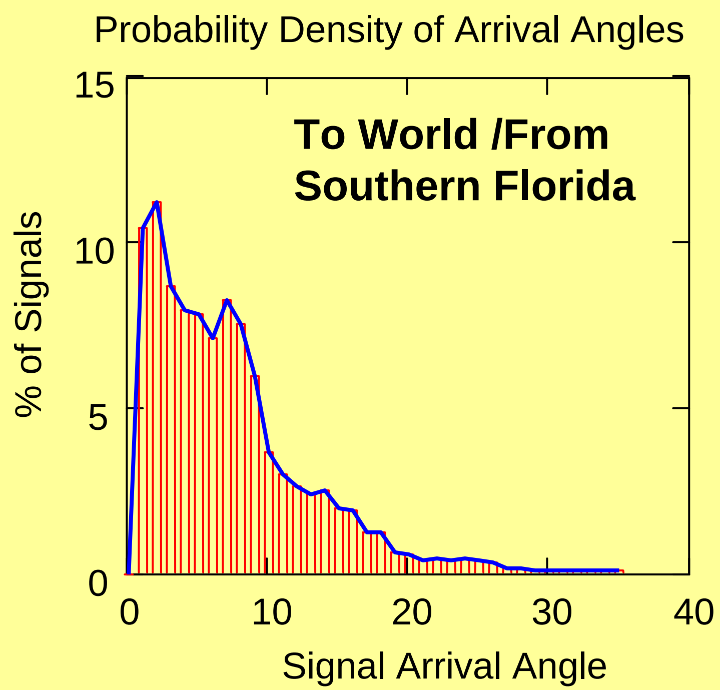
"0 dB" reference is free space (no ground reflection)

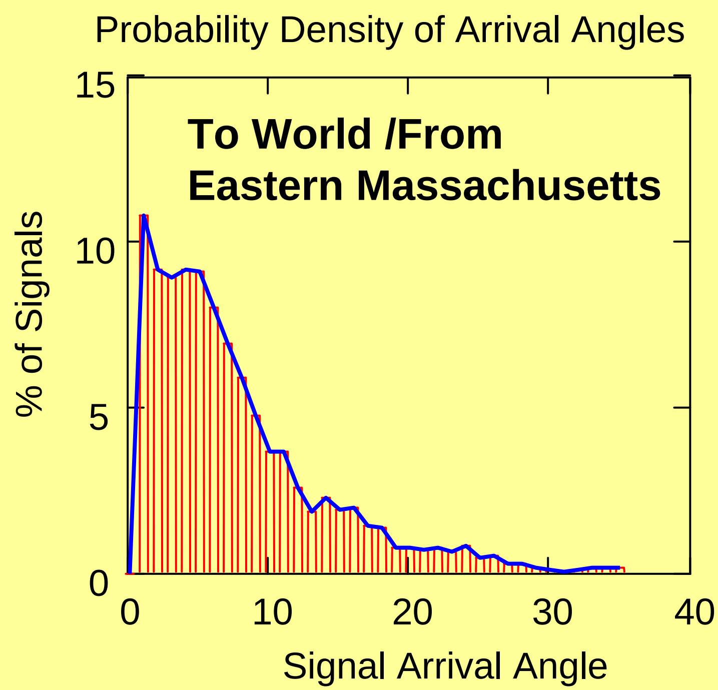
Unique Vertical Standing Waves for each Arrival Angle, Frequency



- 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

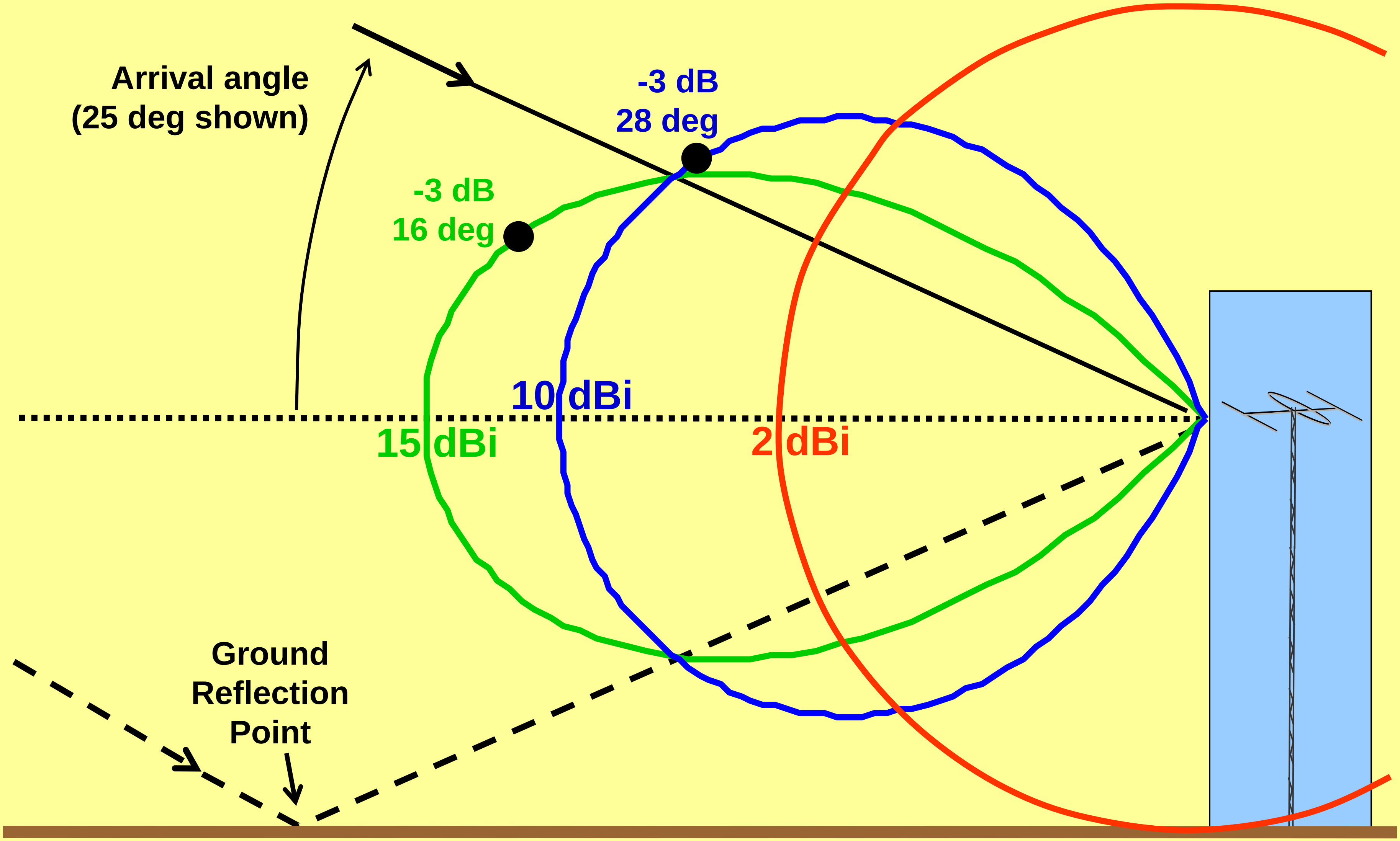
99% are less than 27 deg

3 – 10 deg most important for DX

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

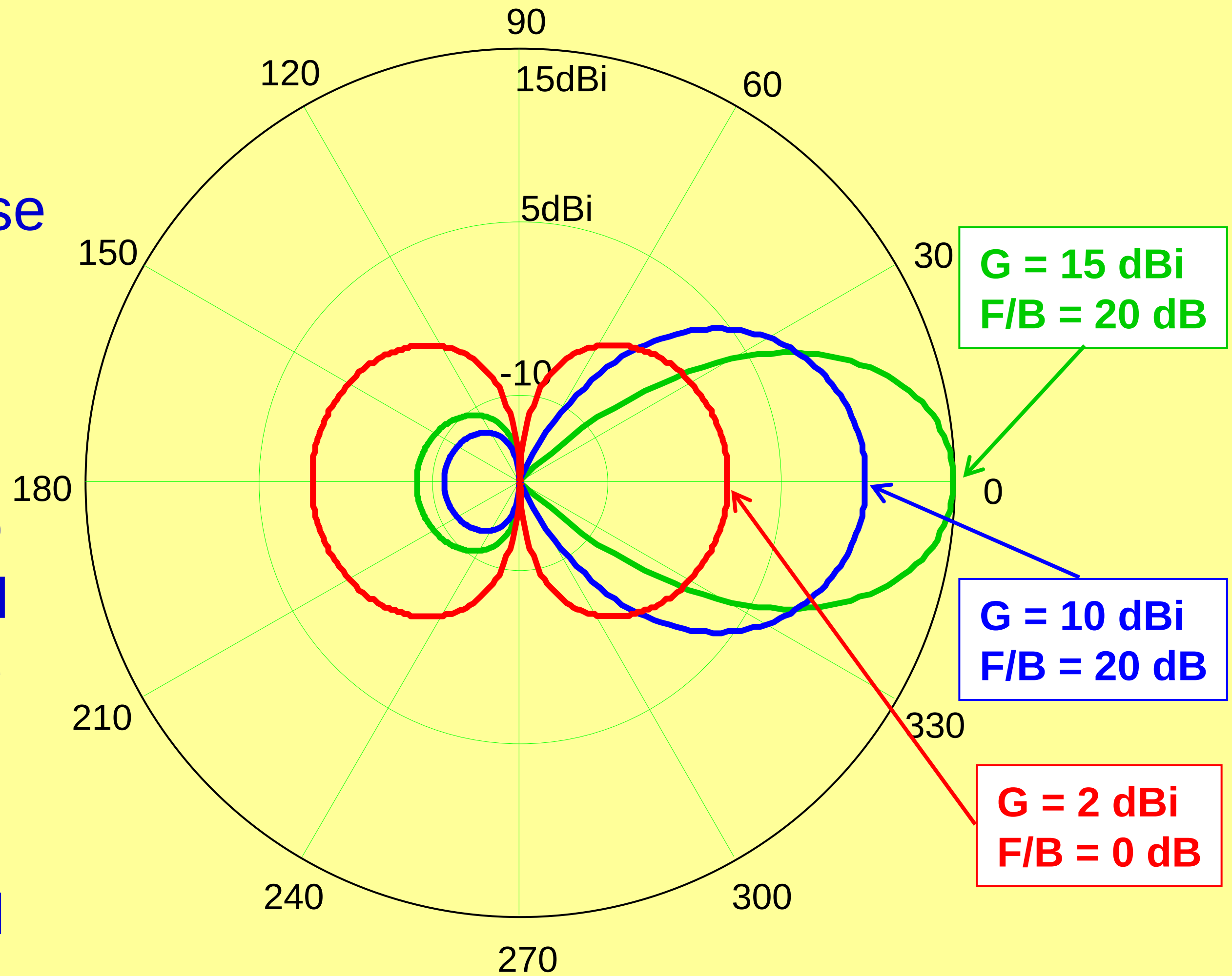
Source: http://www.arrl.org/notes/antbook/yt-files.html

Antenna Gain and Beam Width
Important to Arrival Angle



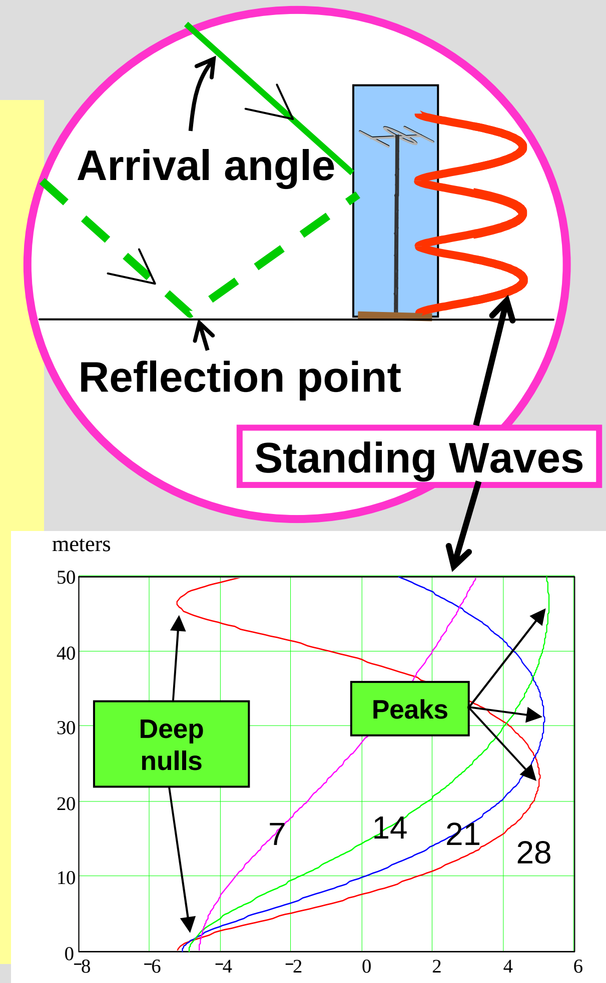
Antenna Azimuth Patterns Important for S/I

- 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

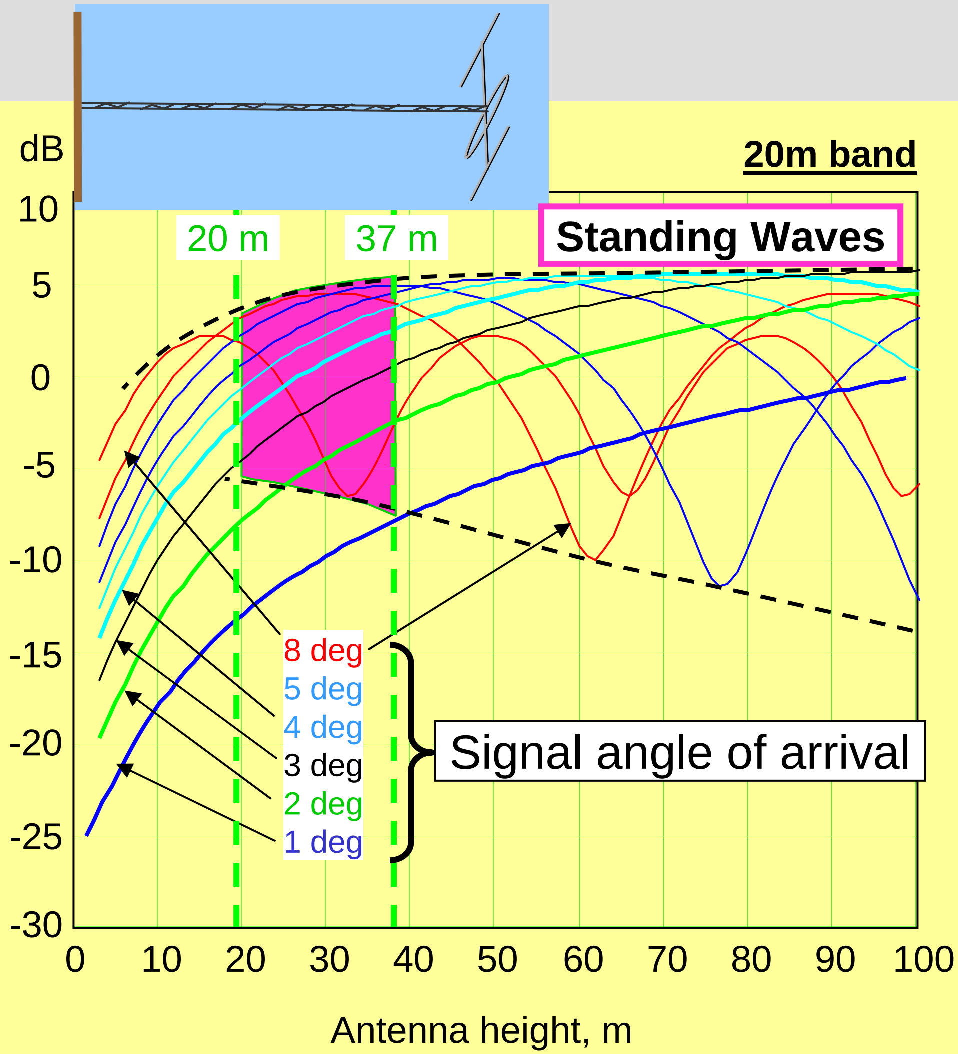


A Quick Recap ...

- 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:
  - Heights of around 55 – 95 ft emerge as optimum range
  - 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 way to measure achievement, and data are readily available

Rules: Work as many DX entities as possible in 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

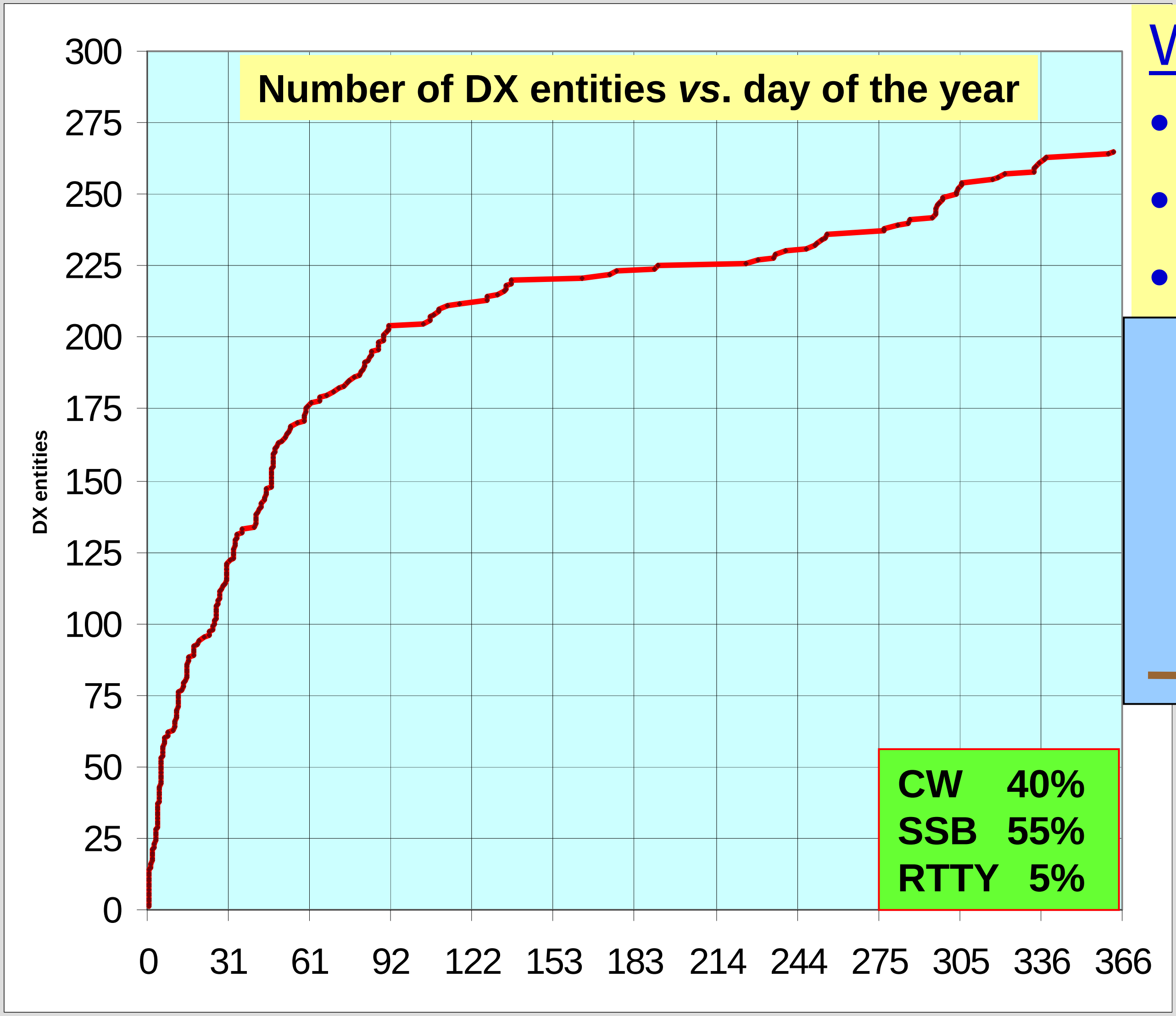
Formula Class Option 2:

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

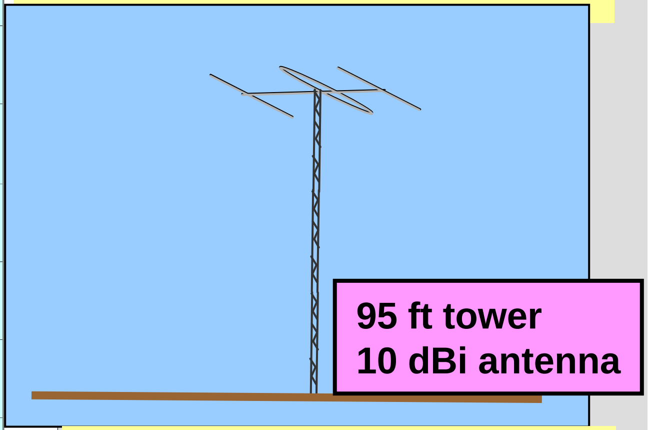
CQ Magazine also sponsors the WPX and WAZ Awards

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

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

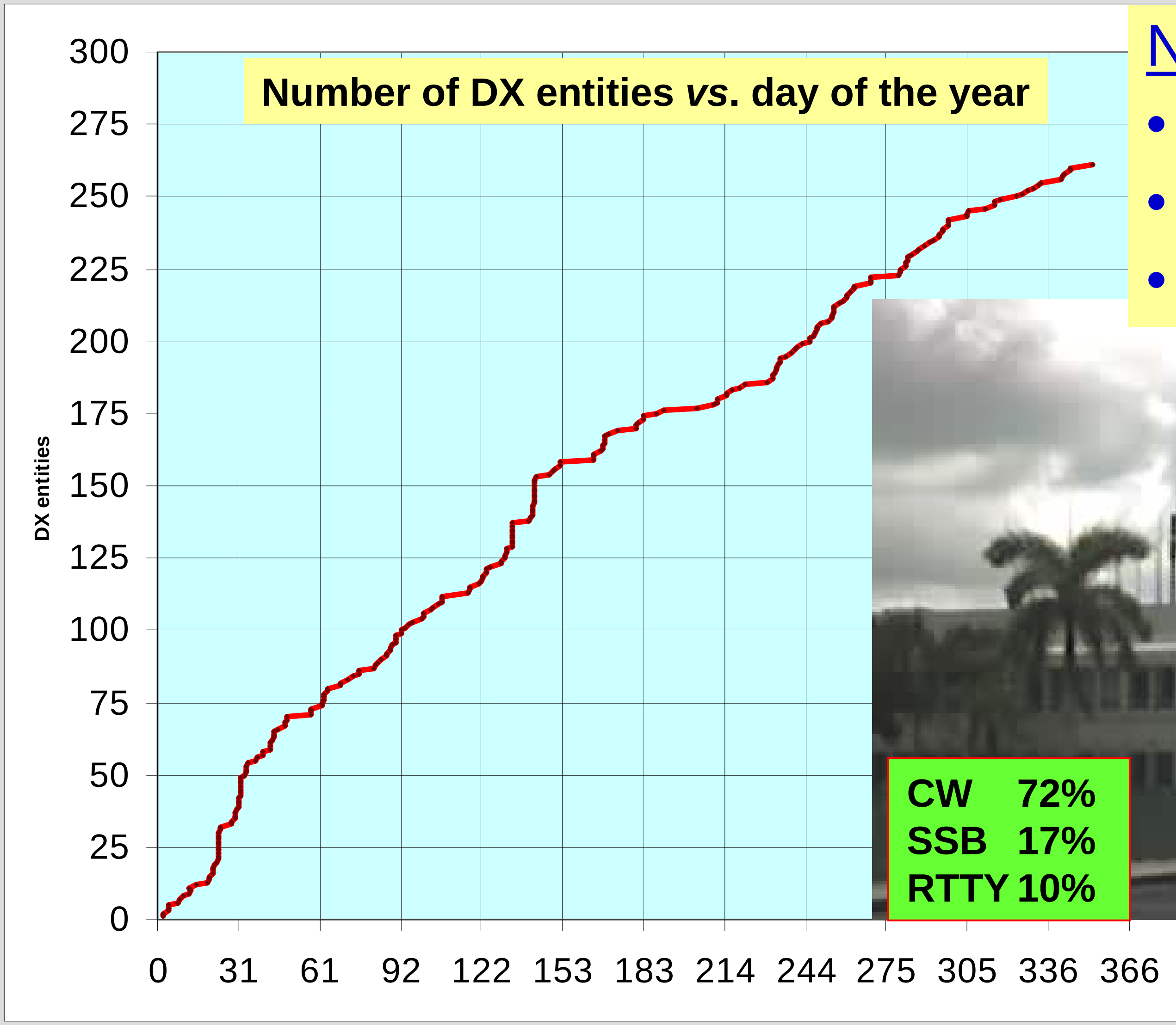


W4QN
- 95 ft tower
- 10dBi antenna
- kilowatt



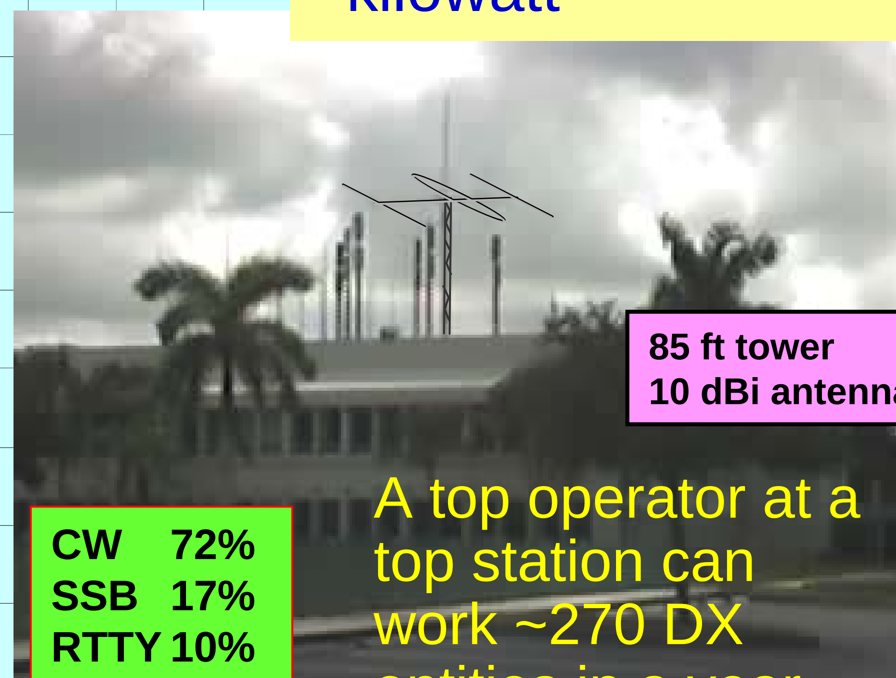
A top operator at a top station can work ~270 DX entities in a year

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



N4II at W4MOT

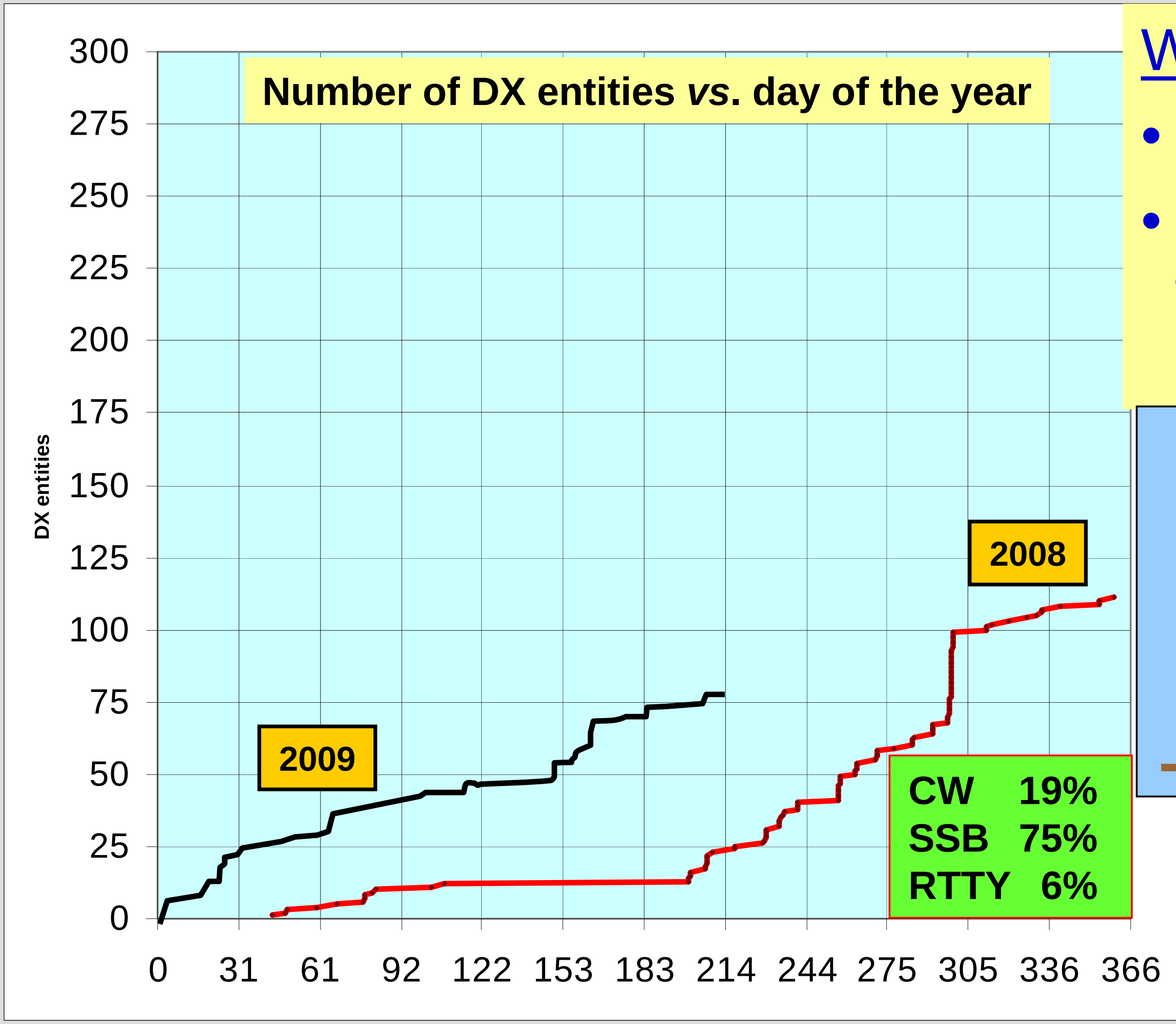
- 85 ft tower
- 10 dBi antenna
- kilowatt



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

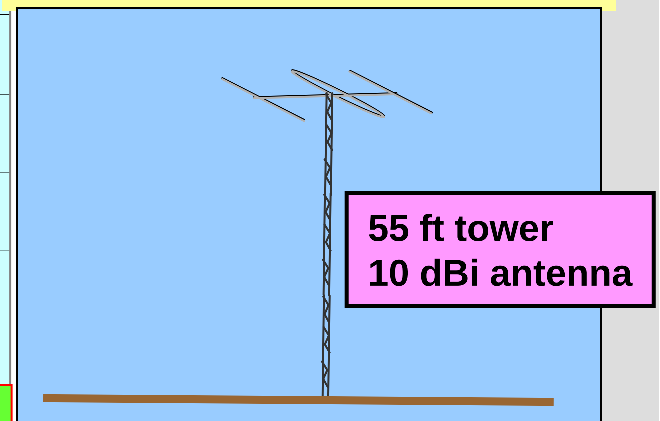
KE4PT photo

With a Moderate Height Station, and Favoring Voice



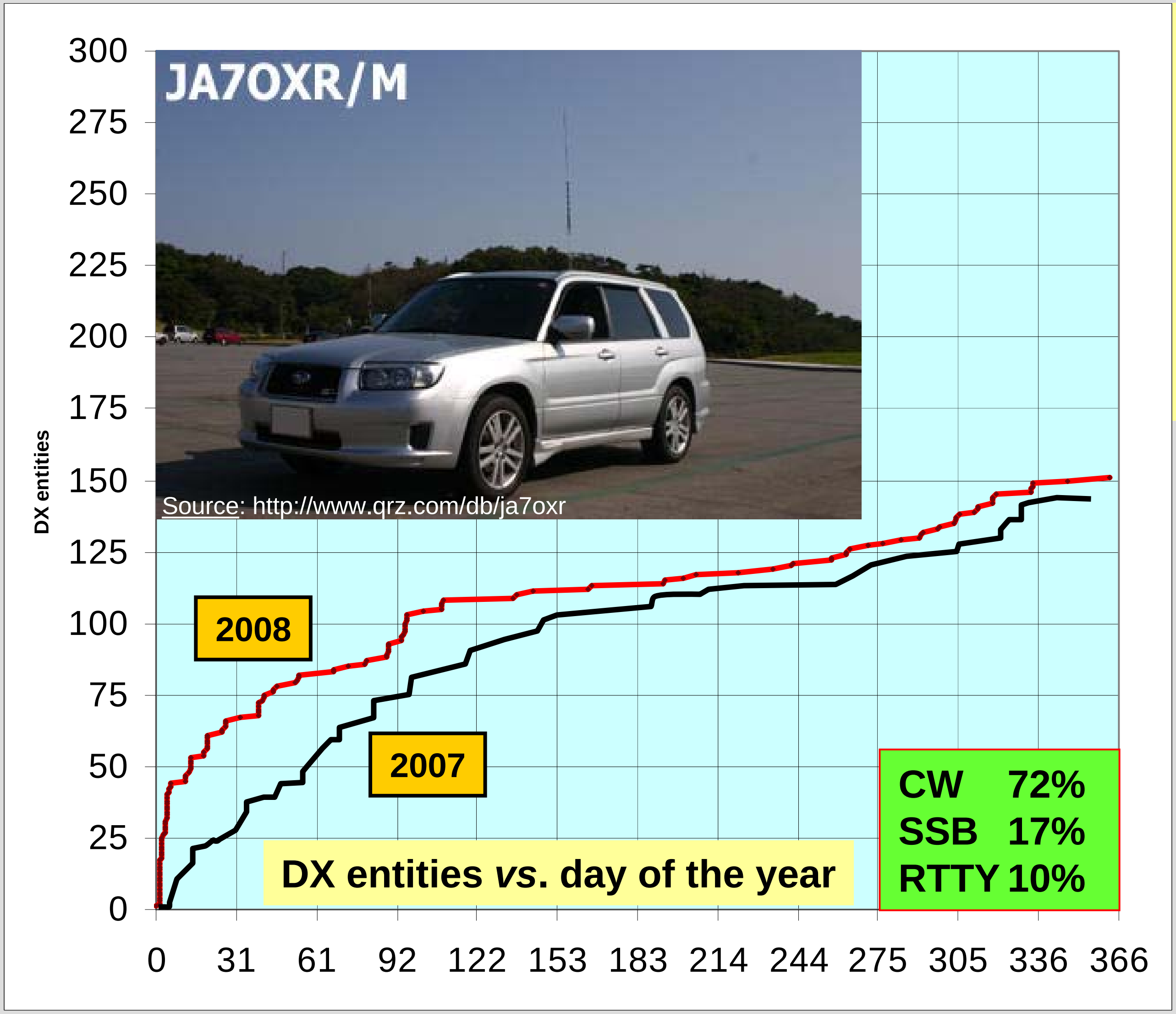
W4DTA

- 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



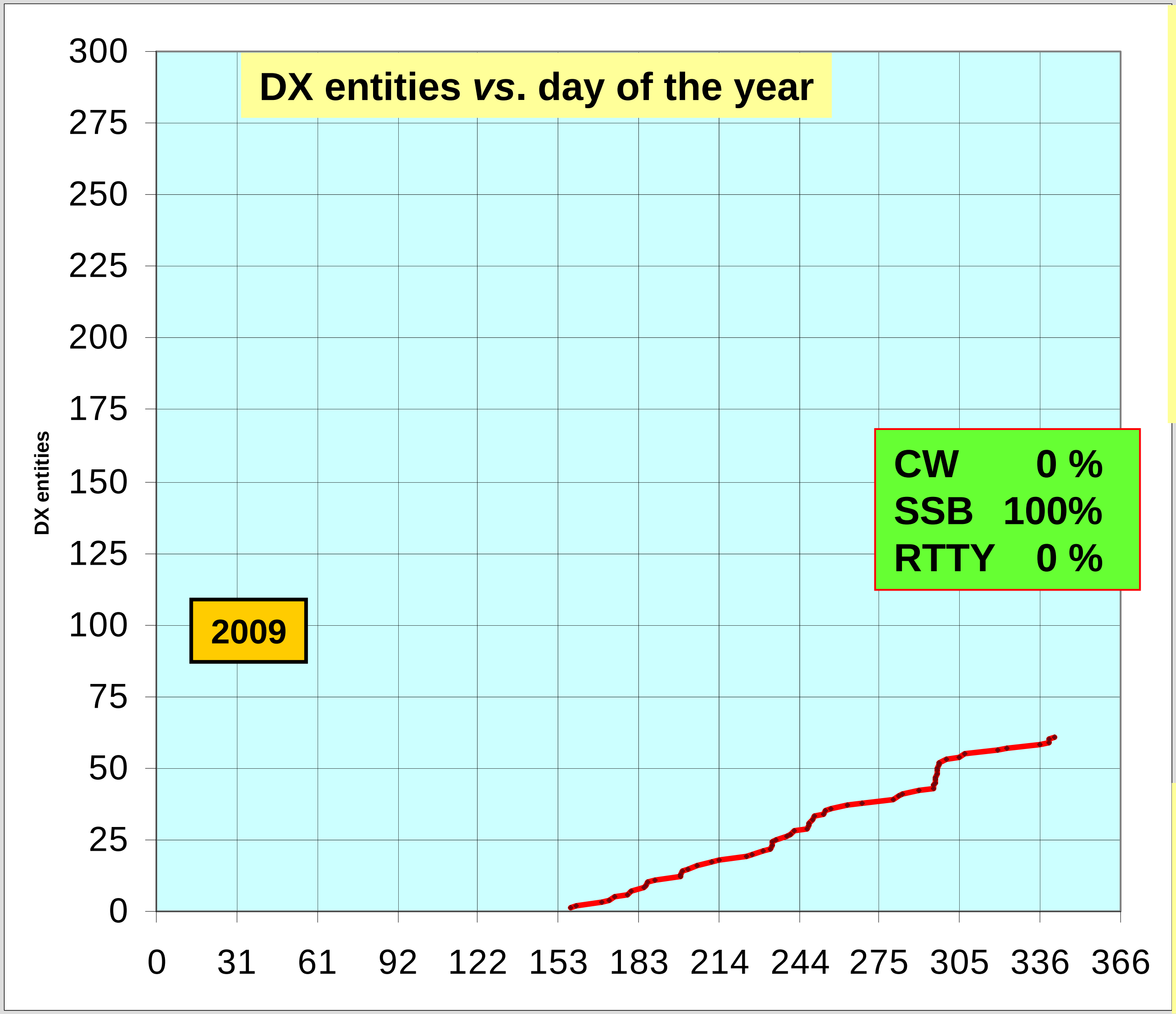
JA7OXR, Nori

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

Vertical mobile antenna

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

Vertical Antenna
40m and SSB only



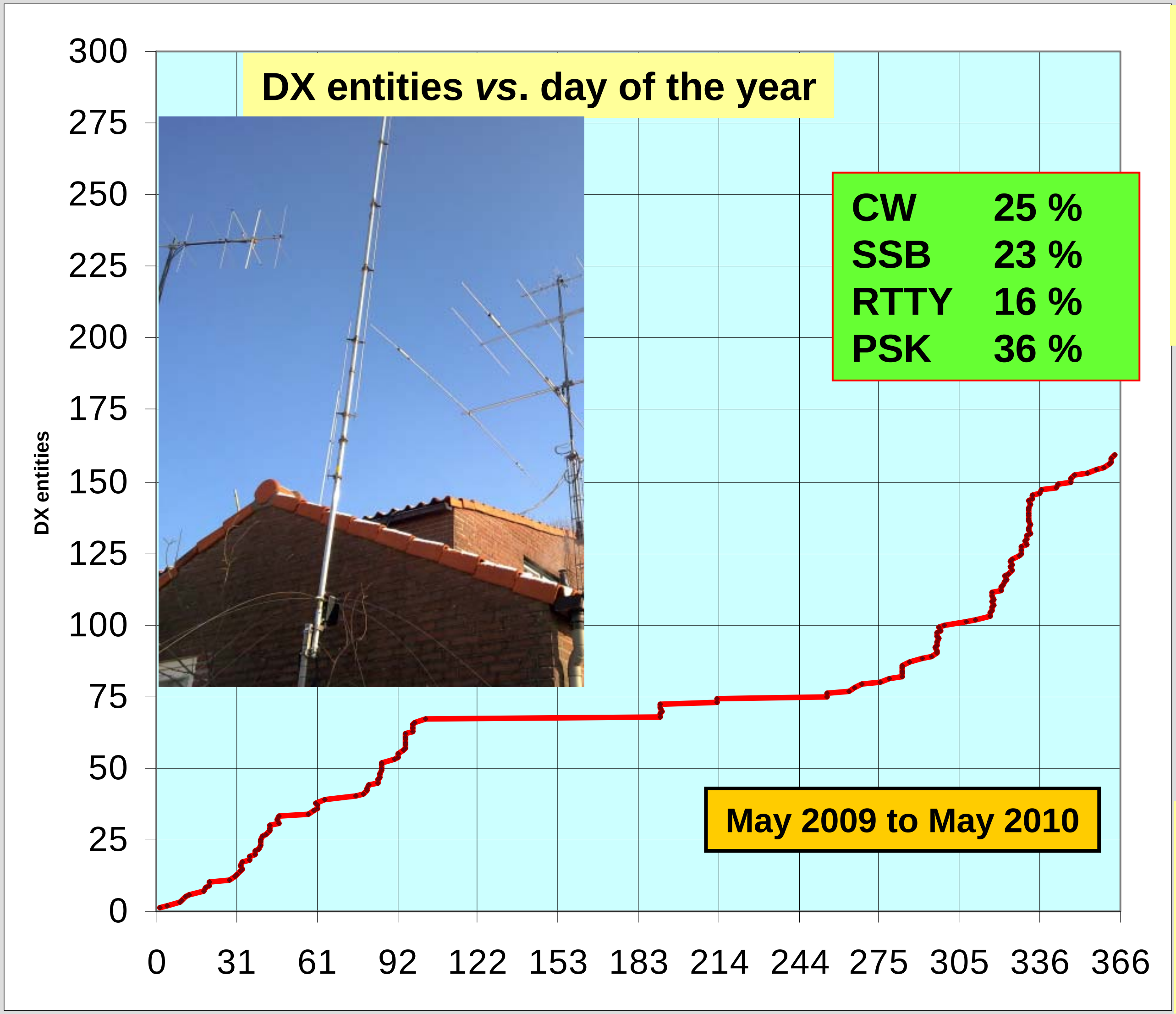
K4VSC

- Vertical
- 100 watts
- 40m SSB only

Vertical antenna

Started in June,
Steady increase

Vertical Antenna



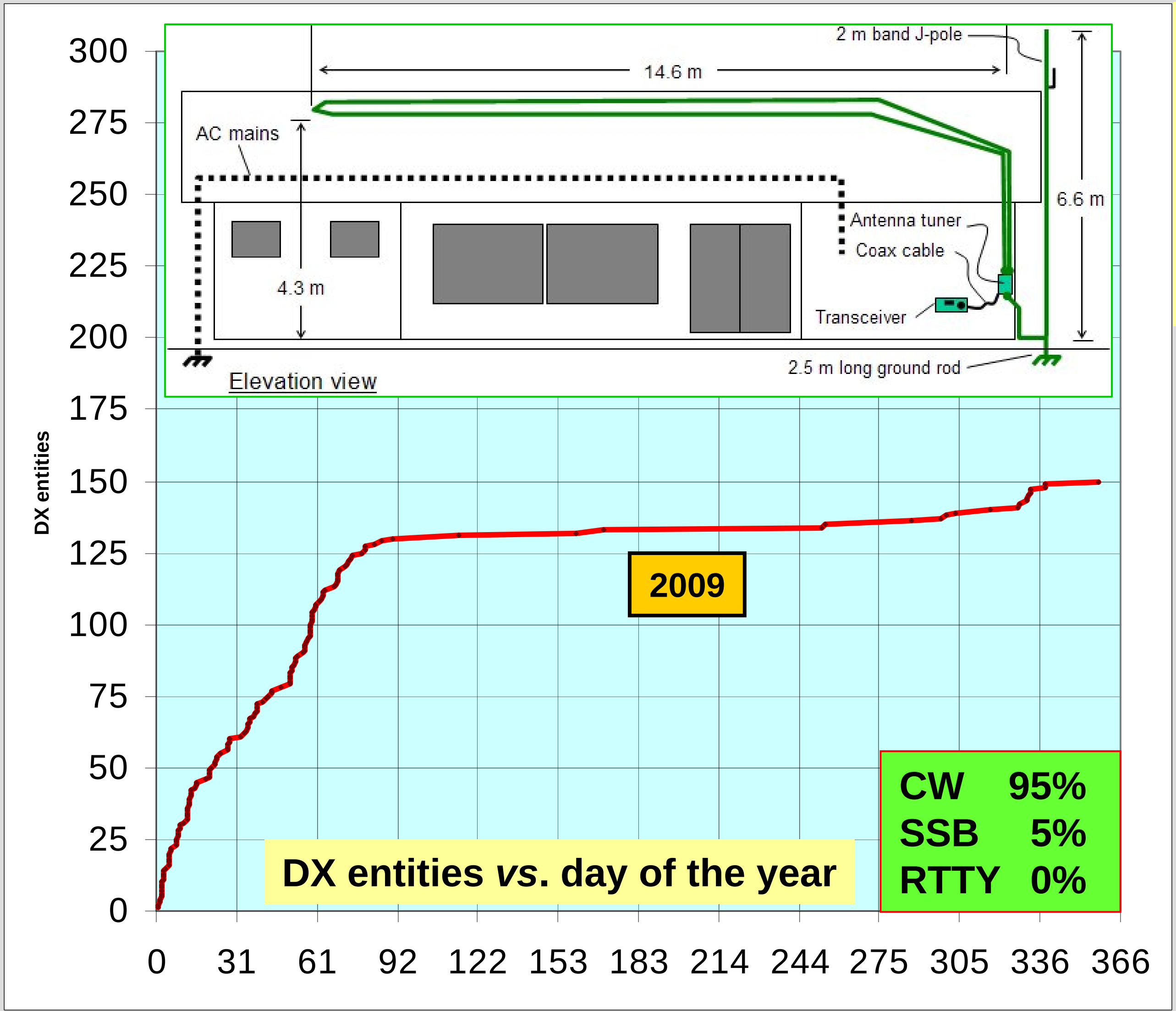
PB7XYL, Anneke

- Vertical
- 100 watts
- 40m – 10m

Vertical antenna

Vertical antenna produced ~160 DX entities in one year

Indoor Antenna Station, Mostly CW



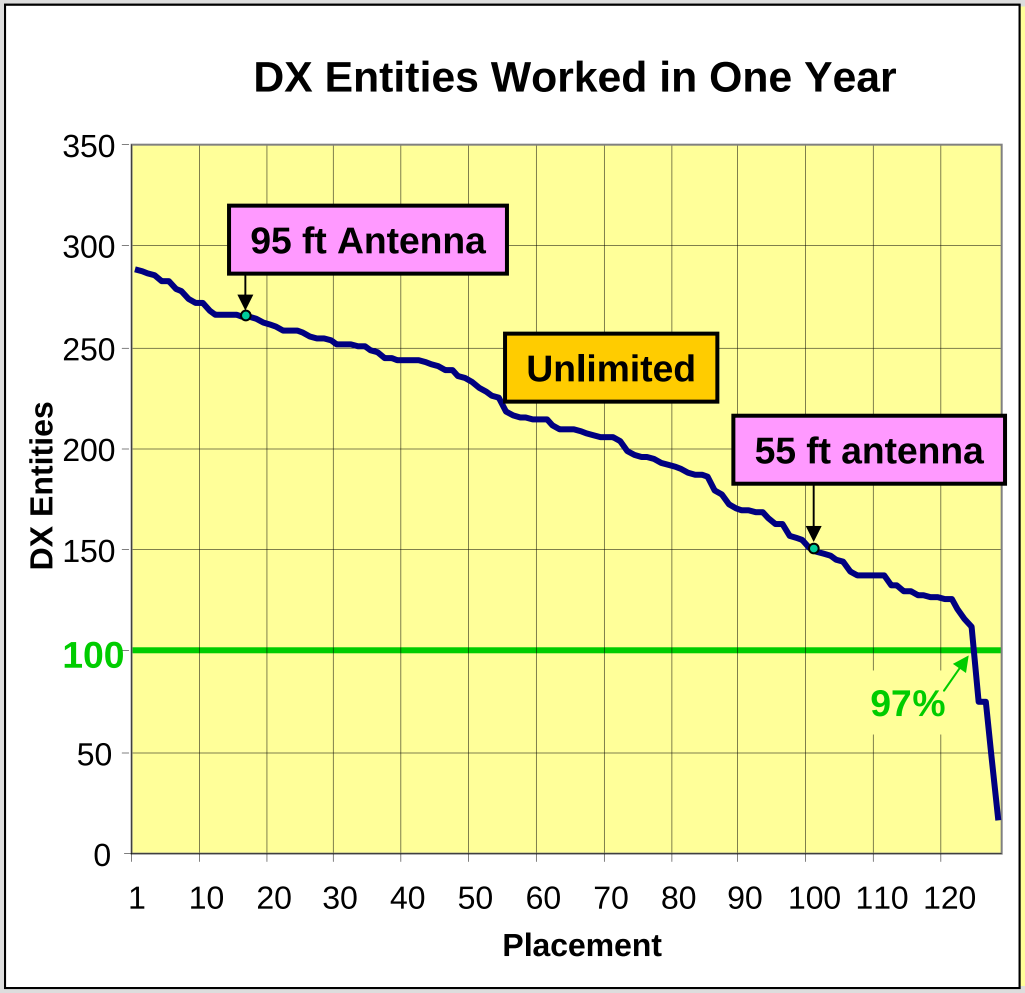
KE4PT, Kai

- Indoor antenna
- ~0 dBi
- 100 watts

Indoor antenna

Modest station with "no visible means of antenna" can work ~150 DX entities in a year

Unlimited: CQ-DX Marathon



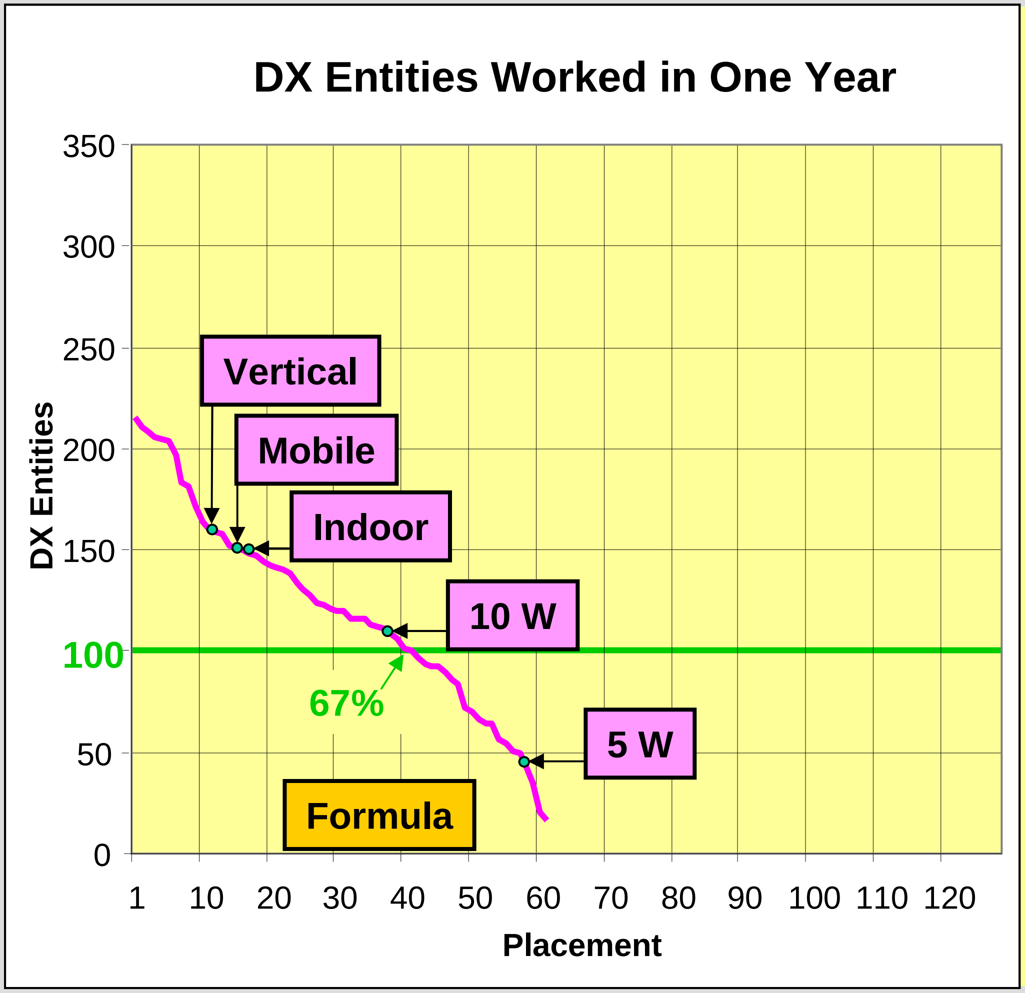
In one calendar year, even with few sun spots ...

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

Formula: CQ-DX Marathon



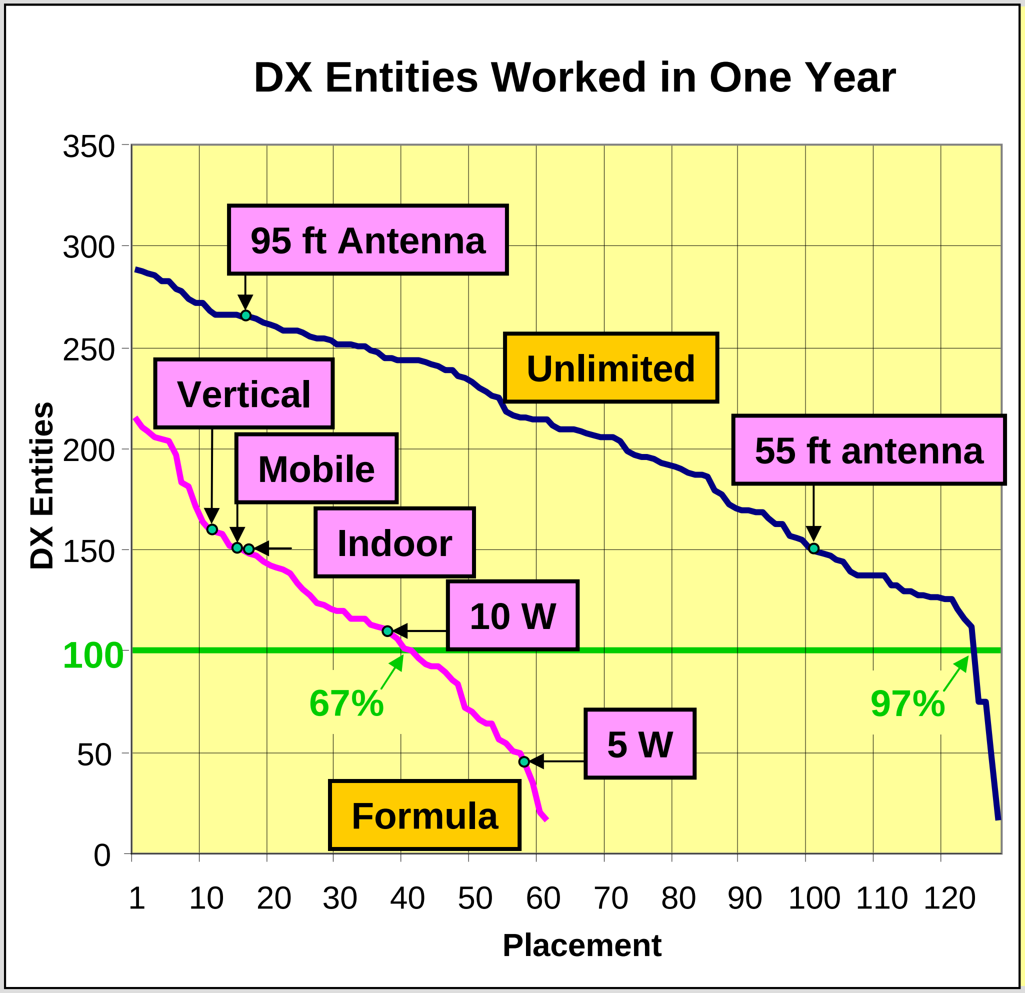
In one calendar year, even with few sun spots ...

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!

Summary: CQ-DX Marathon



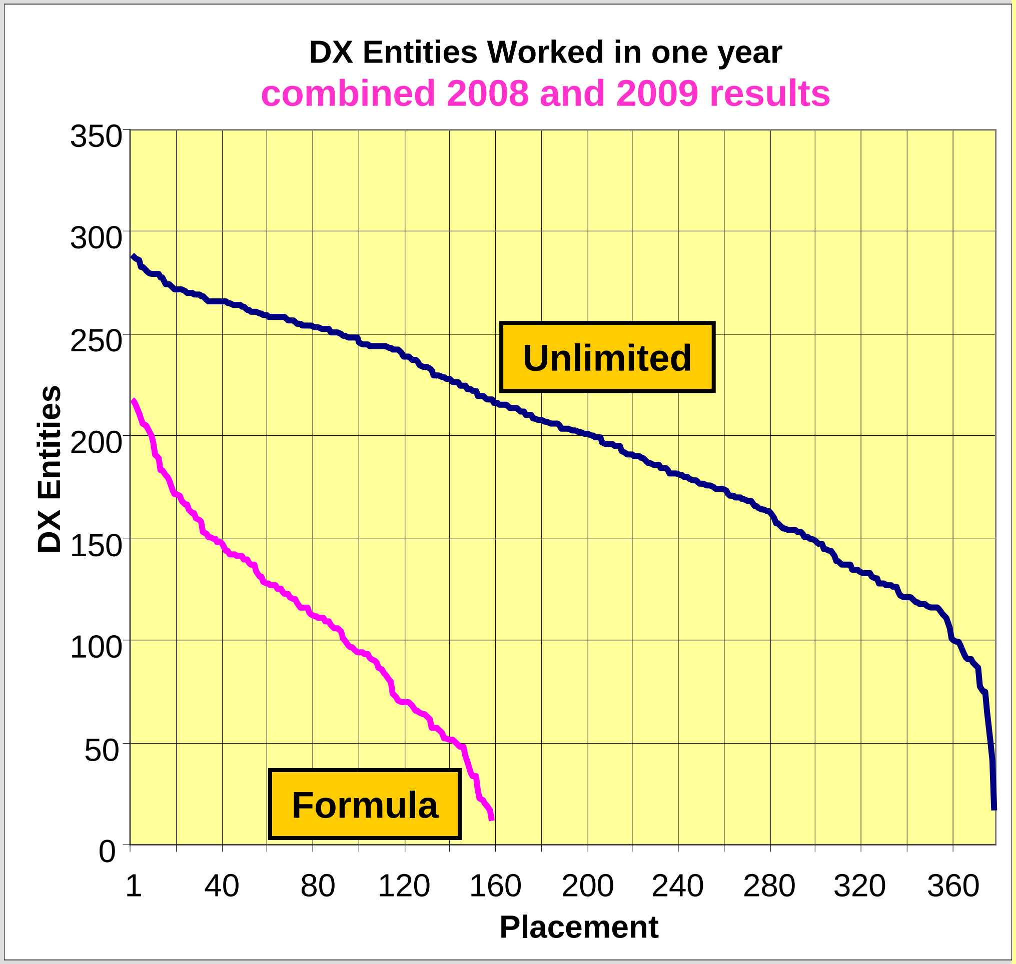
In one calendar year, even with few sun spots ...

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

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!

Summary: CQ-DX Marathon



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

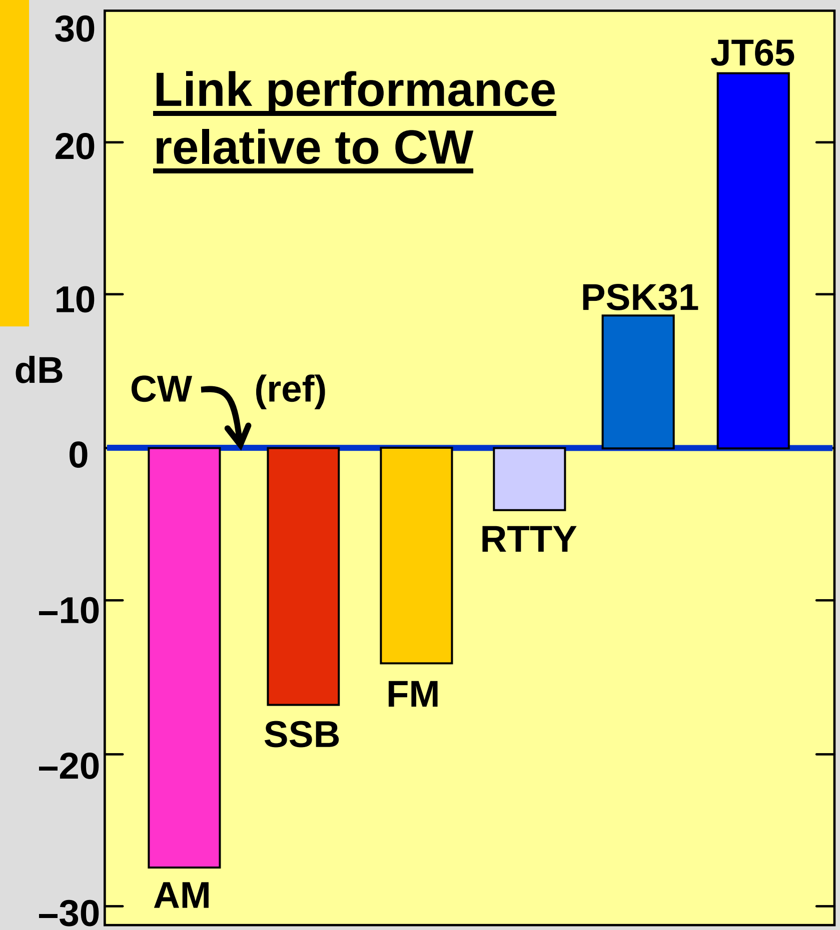
Unlimited Class stations can work almost 300 DX entities in a year: *up to 30 dB link margin advantage over modest station*

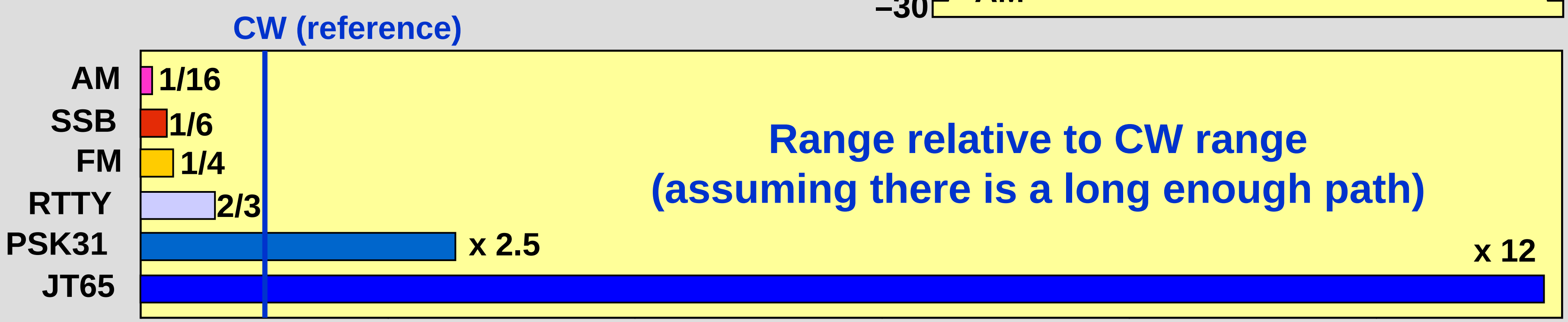
Modest stations 100 watts or less and with no significant antenna gain can work over 200 DX entities in a year

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

Not Really an Antenna issue, but operating mode matters!

For a given <u>Peak Envelope Power</u> all digital modes outperform SSB, some outperform CW





From: K. Siwiak, KE4PT and B. Pontius, N0ADL, *How much "punch" can you get from different operating modes?* (accepted for publication in **QST).**

Antennas: the "take away"

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

- No Surprise That: success rate increases to 97% for Yagis on optimum-height towers, kilowatt, good operator: *flexibility of 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.

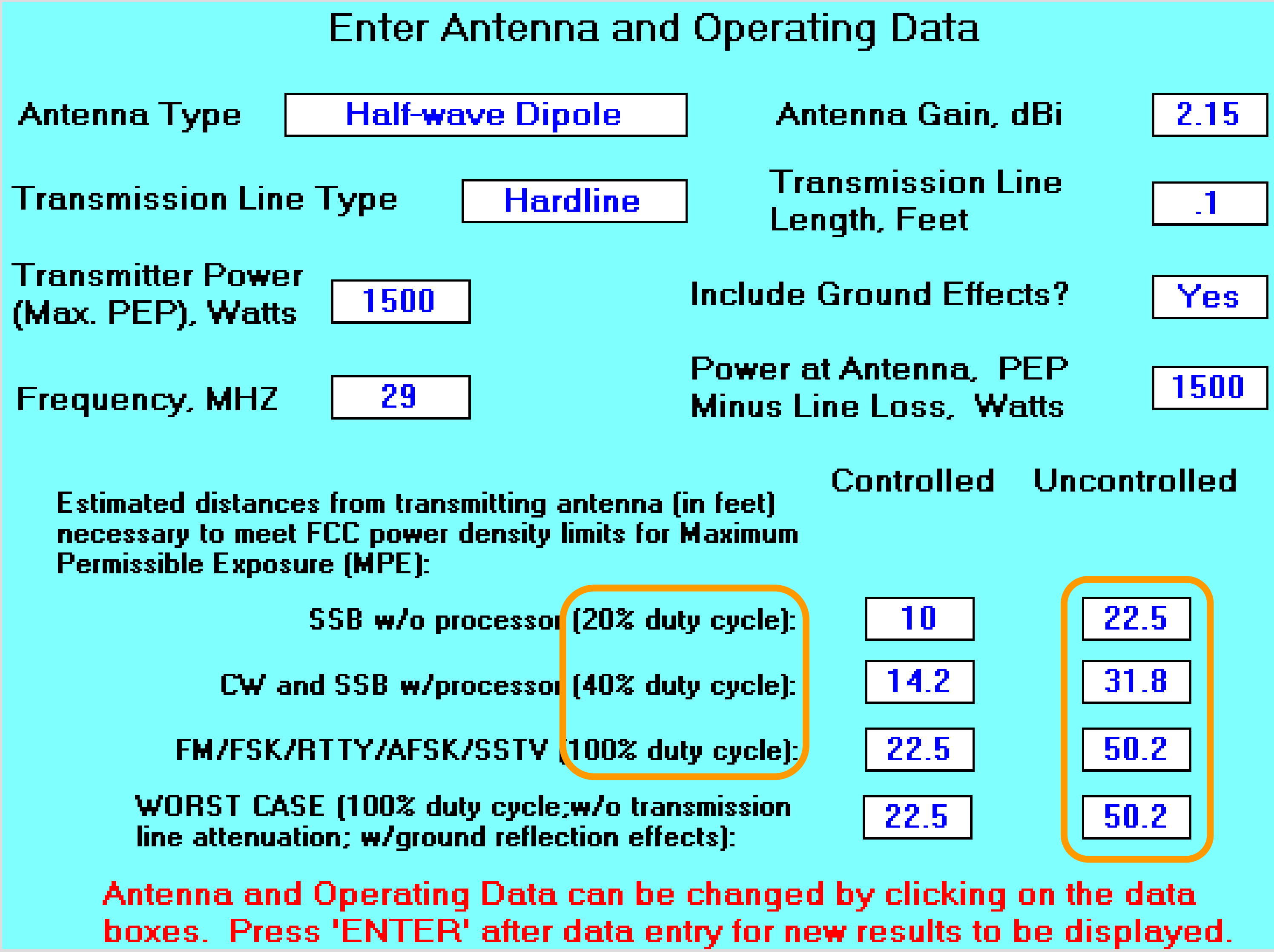
By signing the form you agree to the following *fine-print text:*

"*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."

<u>Without Exception:</u>
<u>All</u> Stations Must Be CERTIFIED

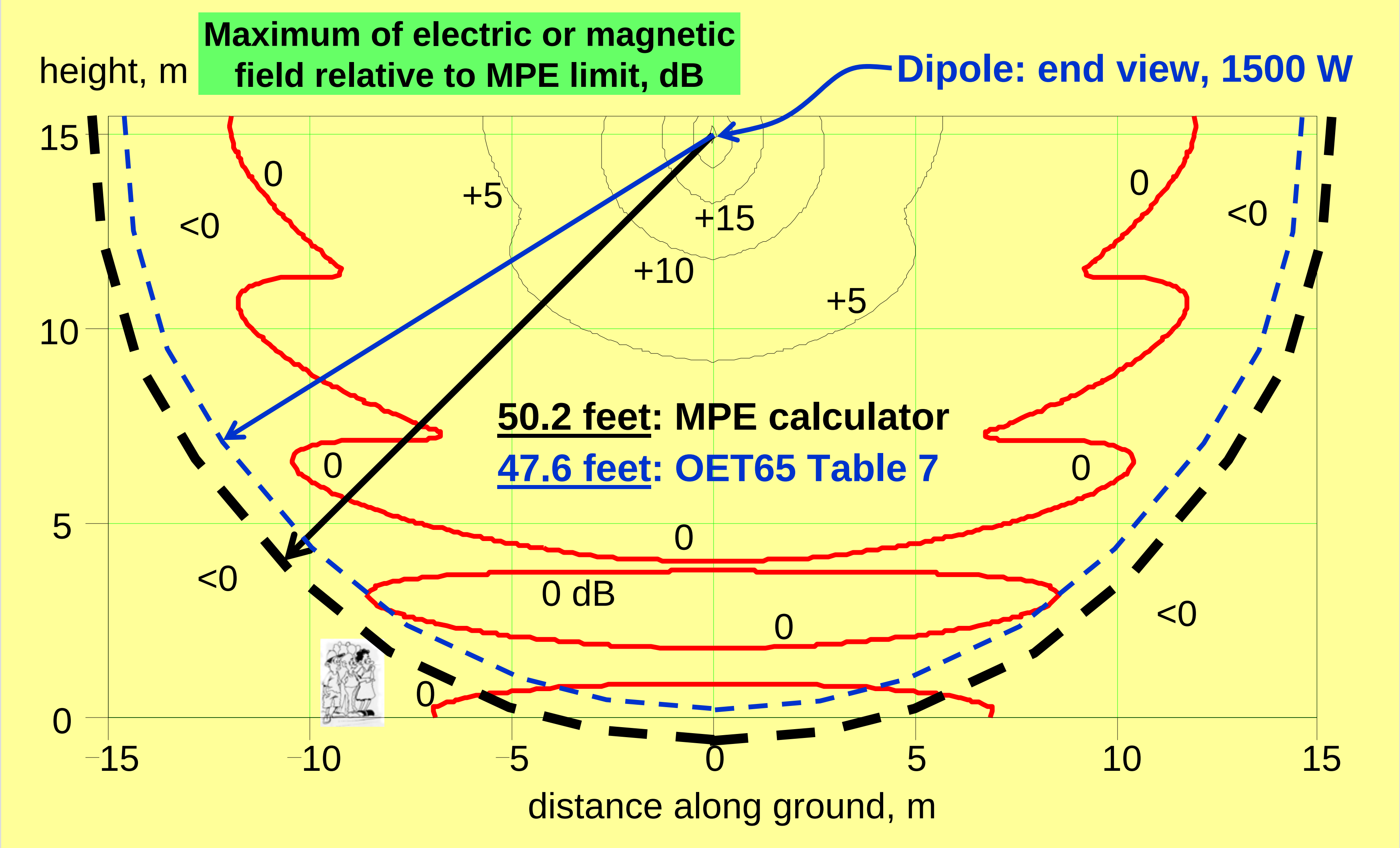
- Basis of RF exposure standards in the regulations
  - § 97.13(c) starts the process for Hams
  - § 1.1310 "Radiofrequency radiation exposure limits"
  - § 2.1093 "Radiofrequency radiation exposure evaluation: portable devices" (20 cm separation)
- Some stations are exempted from *<u>evaluation</u>*

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!

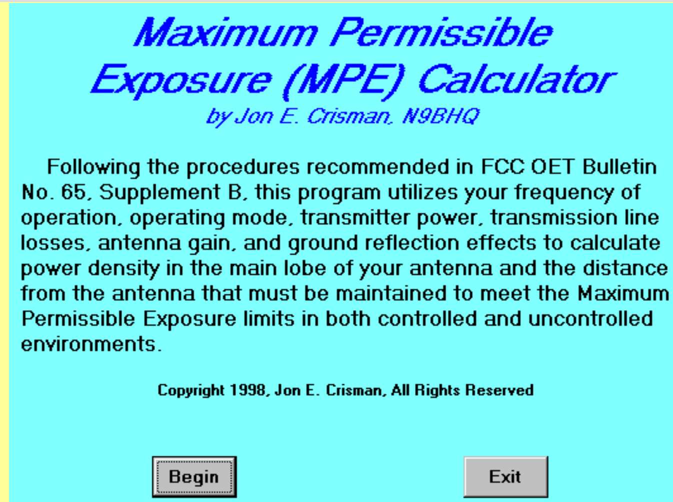
For stubborn cases:

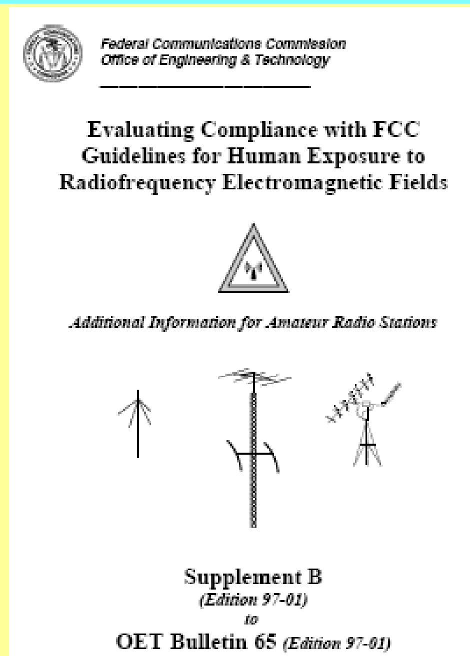
– Use calculations from NEC

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

getting your computer to solve
Maxwell’s equations for you

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 ...

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

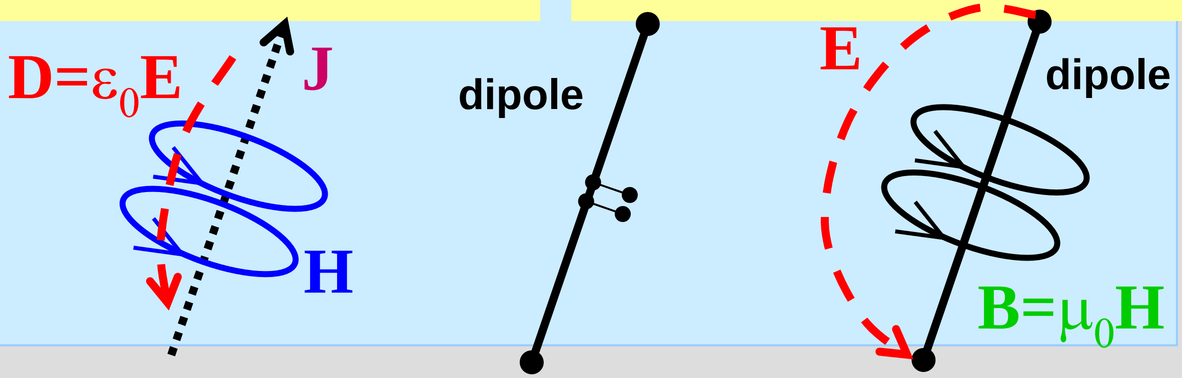
... currents radiate!

What the equations mean ...

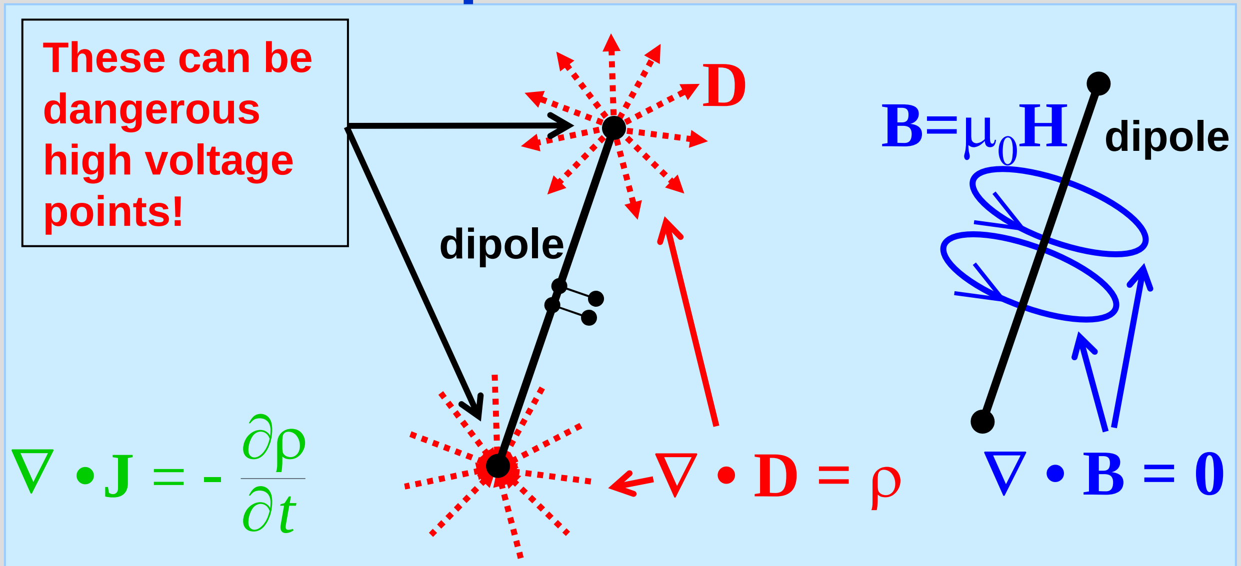
$$\nabla\times\mathbf{H}=\frac{\partial\mathbf{D}}{\partial t}+\mathbf{J} \qquad \nabla\times\mathbf{E}=-\frac{\partial\mathbf{B}}{\partial t}$$

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

- An electric field **E** will wrap around a time varying magnetic flux **B**



What the equations mean …



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

- Electric field **D** diverges from 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

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

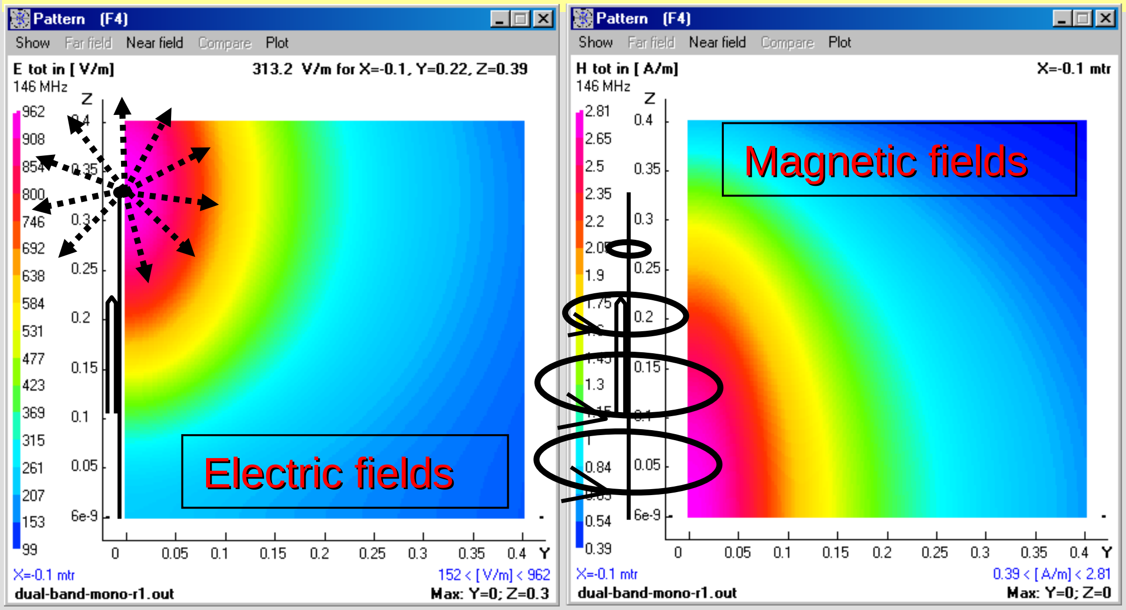
$$\mathbf{A} = \frac{\mu_0}{4\pi} I \Delta l \frac{e^{-jkr}}{r} \mathbf{z}$$

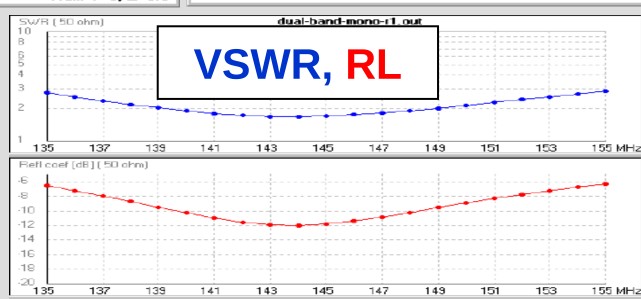
A is a vector potential, gives rise to E, H fields

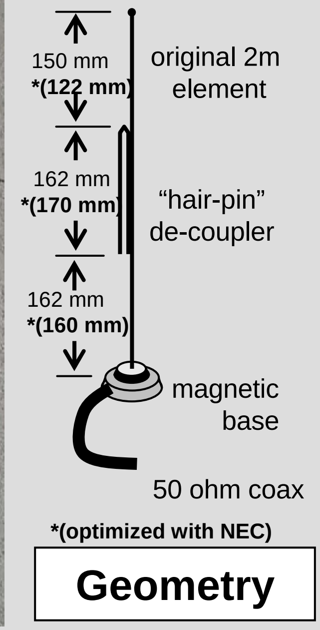
$$\mu_0 \mathbf{H} = \nabla \times \mathbf{A} \qquad \mathbf{E} = -\nabla\Phi - j\omega\mathbf{A}$$

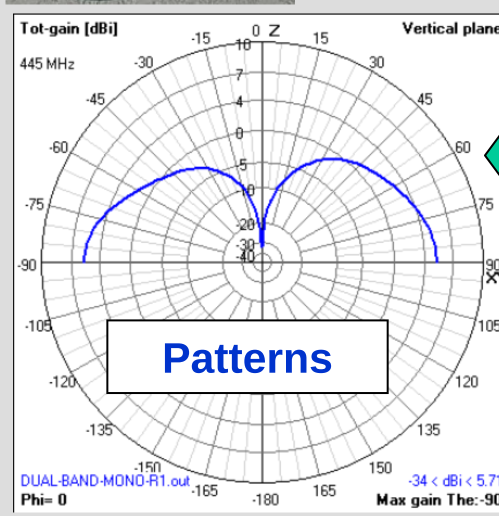
How we use the equations ...

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



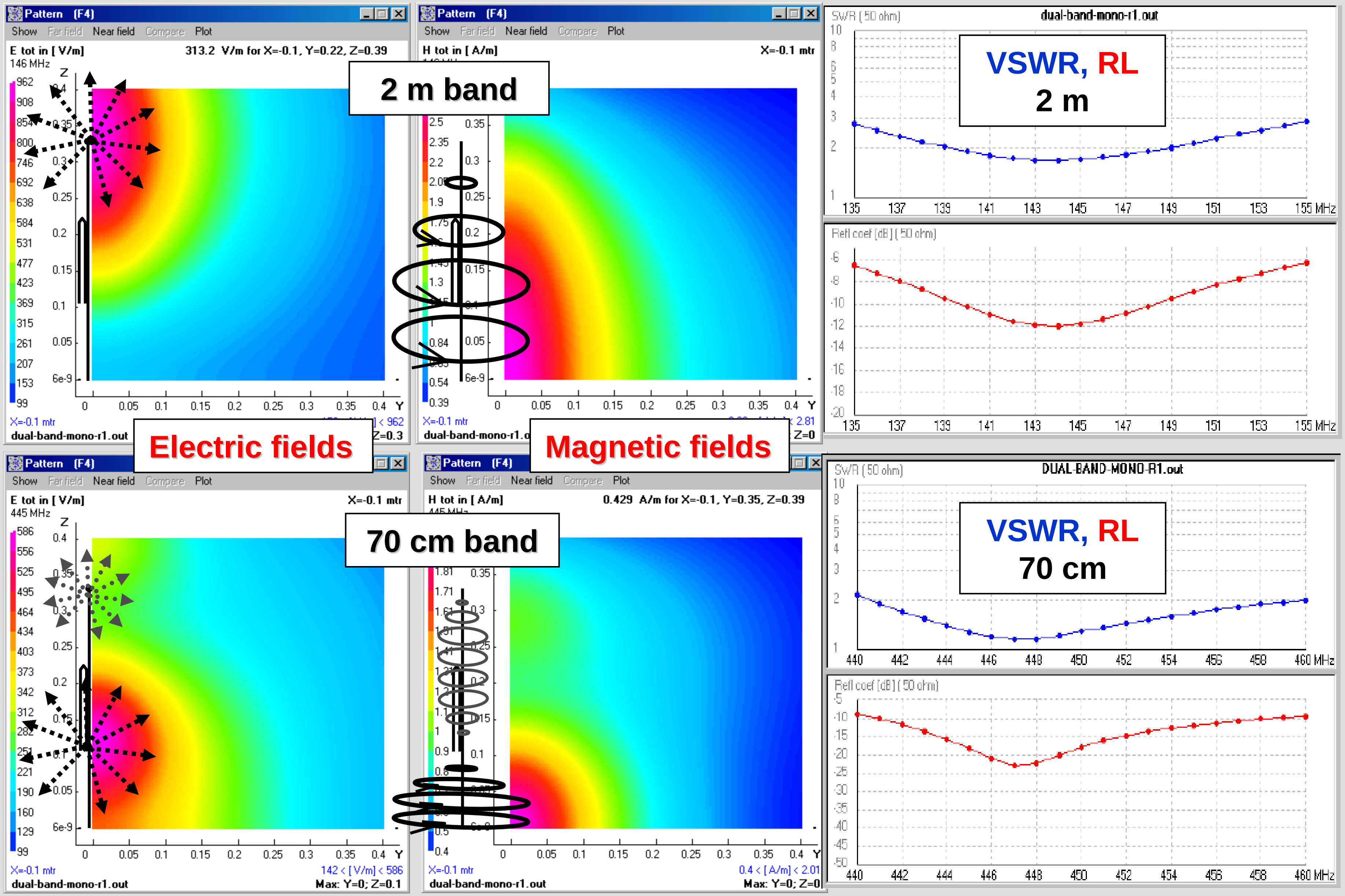






Source: 4nec2 by Arie Voors: http://home.ict.nl/~arivoors/

… and in Two Bands …



QUESTIONS?

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

And God Said ...

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

where on the good Earth ...

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

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

and that ...

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

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

thus ...

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

... and there was light!