WattGuard – a high accurate, easy to use software for 3D calculation of the exposition of amateur radio stations

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Prof. Dr.-Ing. Dr. h.c. Dr.-Ing. E.h. mult. Werner Wiesbeck
Amateur Radio in Germany and World Wide

- Approx. 80,000 radio amateurs in Germany, approx. 2.8 millions worldwide
- Hobby and communication in emergency cases
- License necessary
- Frequency from 135 kHz to 250 GHz
  Transmit power up to 750 W PEP

### Important Frequency Bands

<table>
<thead>
<tr>
<th>Frequency in MHz</th>
<th>Wavelength in m</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.81 – 1.85</td>
<td>160</td>
</tr>
<tr>
<td>3.5 – 3.8</td>
<td>80</td>
</tr>
<tr>
<td>7.1 – 7.2</td>
<td>40</td>
</tr>
<tr>
<td>14 – 14.35</td>
<td>20</td>
</tr>
<tr>
<td>18.068 – 18.168</td>
<td>17</td>
</tr>
<tr>
<td>21 – 21.45</td>
<td>15</td>
</tr>
<tr>
<td>24.89 – 24.99</td>
<td>12</td>
</tr>
<tr>
<td>28 – 29.7</td>
<td>10</td>
</tr>
<tr>
<td>50.08 – 51</td>
<td>6</td>
</tr>
<tr>
<td>144 – 146</td>
<td>2</td>
</tr>
</tbody>
</table>
Typical Amateur Radio Antennas

- Dipole / Wire
- Beam
- Vertical Antenna
- Loop
- Spider Beam
- Cubical Quad
Stationary amateur radio station must be safe
- It has to be assured that the EM exposition is not exceeding the limits for the public areas
- Nearfield and farfield data has to be taken into account as well as ground reflections
- Calculation should be possible for almost all antenna configurations

Software for the calculation of safety distances
- easy to use, fast and accurate
- provides nearfield calculations, ground reflections, superposition of several stations
Basics for EM Field Calculations
Elementary Radiator: Fields of the Hertz’ian Dipol

**E-Feld**

\[
\vec{E}_r = -j\Delta z \frac{\mu}{4\pi} \frac{e^{-jbr}}{r} j\omega \left( 2\frac{j}{\beta r} + \frac{2}{(\beta r)^2} \right) \cos\theta \\
\vec{E}_\theta = j\Delta z \frac{\mu}{4\pi} \frac{e^{-jbr}}{r} j\omega \left( 1 - \frac{j}{\beta r} - \frac{2}{(\beta r)^2} \right) \sin\theta \\
\vec{E}_\psi = 0
\]

**H-Feld**

\[
\vec{H}_r = 0 \\
\vec{H}_\theta = 0 \\
\vec{H}_\psi = j\Delta z \frac{1}{4\pi} \frac{e^{-jbr}}{r} \beta \left( 1 - \frac{j}{\beta r} \right) \sin\theta
\]

\[\theta = 90^\circ \quad \psi = 0^\circ \]

~1/r, ~1/r^2, ~1/r^3
Antenna Near Field to Far Field Transition

Radiation characteristic

- reactive nearfield
- radiating nearfield
- radiating farfield

Basic modes
Higher modes
Reference plane

Range:
- 0
- λ/2π
- 2D²/λ

λ/2π
2λ
10λ
2D²/λ
50D²/λ
Transition Near Field – Far Field Fitting $C_{\text{fit}}(r, \theta, \psi)$

- Antenna pattern depends on distance

- Separate fitting für near field and far field

\[
C(\theta, \psi) \quad \text{Far field} \\
C_E(r, \theta, \psi) \quad \text{Near field} \\
C_H(r, \theta, \psi) 
\]

$C_{\text{fit}}(r, \theta, \psi)$ describes angle dependancy of far field und near fields

with numerical available data $C_{\text{fit}}$ can be calculated directly

- else: approximation by similar antennas
- approximation of near field pattern by far field in certain distances
- in close vicinity isotropic approximation (worst-case)
Determination of the Reflected Field

Reflection factor:
- $|r| = 0.7$ (moist soil)
- $|r| = 0.25$ (dry soil)
- $|r| = 1$ (grazing incidence)

<table>
<thead>
<tr>
<th>subsurface</th>
<th>permittivity $\varepsilon$</th>
</tr>
</thead>
<tbody>
<tr>
<td>dry soil</td>
<td>2 ... 10</td>
</tr>
<tr>
<td>moist soil</td>
<td>30</td>
</tr>
<tr>
<td>grass</td>
<td>10 ... 15</td>
</tr>
<tr>
<td>concrete</td>
<td>6.4 ... 7</td>
</tr>
</tbody>
</table>

$E_{total} = |E_{direct}| + |E_{reflect}|$

- reflected field is calculated by mirroring method
- worst-case approximation: total reflection, but can be varied in a certain range (0.3 – 1)
- ground reflection can also be considered using NEC data
Calculation of the Safety Area with WattGuard
Safety Area

- Region between ground surface and height of e.g. 3m is considered
- Orthogonal projection to ground surface
- Safety distance is a function of the elevation angle

Calculation of the maximum of the safety area in Main Beam Direction (MBD)
- Is there a building in this area?
- Are there any persons in this area?
WattGuard Software

Definition in cooperation with the German Federal Network Agency in clearance with the Radio Amateur Association (RTA)

Input Data
- Antenna Data
- Frequency
- Position/Height
- Orientation
- Transmit Power
- Cable Attenuation
- Modulation

Exposure Limits

Calculation
- exact 3D field calculation \((E, H)\) if data available
- else: fitted distance function \(F(r)\) and fitted antenna pattern \(C(r,\theta,\psi)\)
- Far field, near field, ground reflections

Safety Area (3D)
Program Start

Federal Network Agency
Section 414

V 0.96 (public beta 4, no notification) released 16.12.2011

Welcome to Watt Guard.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Assistant</th>
<th>Extended mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>Display of the safety zone</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Display of the el. and mag. field strengths</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Safety distance in user-defined planes (additional to)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Rotation about the antenna longitudinal axis (polarization)</td>
<td>✓</td>
<td>✓</td>
</tr>
<tr>
<td>Adjustable factor for ground reflection</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simultaneous operation of multiple antennas</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Create and edit additional antennas</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The choice of the mode has no influence on the calculations of the protection area!

assistant  extended mode
Program Step 1/5: Antenna Data

built-in antennas

Overview
Integrated Antennas

- Antennas with Gain Data: approx. 500
- Antennas with Pattern Data: approx. 130
- Antennas with NEC-Data: 270

- Pattern- or NEC-Data: Exact Calculation of Safety Area
- Gain Data: Isotropic Approximation-> worst-case-consideration
- Antenna Base in Coordination with Radio Amateurs and Fed. Network Agency
Program Step 2/5: Position Data

Position and Rotation

<table>
<thead>
<tr>
<th>Position</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>North + / South</td>
<td>0.00</td>
</tr>
<tr>
<td>East + / West</td>
<td>0.00</td>
</tr>
<tr>
<td>Height above ground</td>
<td>10.00</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Main beam direction</th>
<th>min.</th>
<th>max.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Azimuth Y [°]</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>Elevation Θ [°]</td>
<td>90</td>
<td>90</td>
</tr>
</tbody>
</table>

Ground Factor (1.3 – 2) | 2.00

Hints
Please enter the antenna position in relation to the reference point (position of the first antenna A). If there is only a single antenna location, please enter 0 for North/South and East/West. If you want to calculate for multiple antennas, enter the position for the following antennas relatively to the first antenna.

A sketch of the selected antenna class illustrates the antenna’s orientation.
Program Step 3/5: Modulation, Transmit Power

<table>
<thead>
<tr>
<th>Data input</th>
<th>Antenna A</th>
<th>Delete Antenna</th>
</tr>
</thead>
<tbody>
<tr>
<td>Step 1: Antenna model</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 2: Antenna position</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Step 3: Transmitter</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 4: Cable</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Step 5: Calculation</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Transmit Scheme (VDE 0848 Part 3-1/A1):**
- CW
- AM
- TY
- DTX
- SSB
- FM
- CSM
- all

**Modulation and Transmit Power:***
- Tx6 – Rx6
- Tx4 – Rx2
- Tx2 – Rx4
- Tx3 – Rx1
- Tx3 – Rx3
- Tx1 – Rx5

**Transmit Power PEP [W]:** 100.0

**Hints:**
Please enter the operation mode and transmission power.

**Transmission mode:**
Enter the modulation type. If "all" is chosen, the worst case is used for calculating the guard distance.

**Federal Network Agency Section 414**

**-Antenna:**
- Antenna: FB-33
- Antenna Gain [dB]: 8.64
- Field Data: NEC

**Antenna location and direction:**
- Main Beam Direction: 0.0
- Antenna height: 10.00

**-Sender:**
- Operation Frequency: 28.9
- Transmit Power PEP [W]: 100.0
- Modulation and Tx/Rx-Cycle SSB 6/0
- Cable Losses [dB]: 0.00
- EIRP [W]: 766

**-Result:**
- Safety Distance (Pers) *
- Safety Distance (HSM) *
* from feed

Bundesnetzagentur
Referat 414

Institut für Hochfrequenztechnik
und Elektronik
Program Step 4/5: Cable Attenuation

Hints:
Please choose the cable in use and enter the length. You can also enter additional attenuation values for connectors etc. (e.g., 0.2 dB per connection).

Cable and additional Attenuation
Program Step 5/5: Safety Area

Safety area is calculated in 3D and can be plotted in horizontal and vertical cutting planes.

Calculation and Results

Field Area
- Horizontal (0 – hmax)
- Vertical

Calc. Height [m]:
- 10.00
- 30.00

Calc. Size [m]:
- 30.00

Guard Area (Pers.)

Guard Distance: 5.85 m

Pos: (-4.61, -13.35, 10.00)
Summary Assisted Mode

- totally free of charge
- license free
- can be downloaded from BNetzA server (and ITU – if possible)
- no special equipment required
- runs on nearly every PC
- large antenna base, can be extended
  - approx. 95% of the typically used amateur radio antennas are covered
- small program, no complicated installation needed
- easy to handle without special knowledge about electromagnetics or special training
- fast and accurate
Why WattGuard?

- Approved and accepted calculation method
- Easy to use with user guidance in Assisted Mode
- Enhanced Mode for experienced users
- Large antenna base
- Modular: further antennas, different exposure limits and additional propagation models are easy to integrate
- Fast 3D calculation of the safety area with near field consideration
- NEC data can be imported for taking into account the environment
- Export function for graphical display of safety area
- Display of field strengths possible
- Simultaneous operation of multiple antennas or stations
- System/platform independent software