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ESTIMATION AND REDUCTION OF WEATHER RADAR SAFETY DISTANCES

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1. INTRODUCTION

The siting of a weather radar always requires a safety analysis, which determines the minimum distances necessary to prevent RF hazards. The analysis has a considerable influence on the selection of important parameters of the infrastructure of the radar site, like the height of the radar tower. It may even exclude a preselected site i.e. if occupied buildings are too close.

Because of the implications of the safety analysis it is important to have a simple method which provides reliable estimations of the field strengths in the vicinity of the radar antenna. The estimations must have a sufficient safety margin, so that measurements of the field strengths which are performed during the acceptance testing of the radar do not question the selection of the site or the height of the antenna tower.

Such a method is presented in this paper. It is based on simple yet accurate approximations of the field strengths in different regions around the radar antenna. In particular the problem of the far-field equation which gives unrealistic high amplitudes close to the antenna is addressed in a practical manner without falling back on numerical simulations.

Most RF-related safety standards allow a long-term averaging of the radiated field strengths, typically over 6 minutes. This fact can be advantageous in order to reduce the safety distances. Because all weather radars are permanently scanning in azimuth (and elevation), each building in the vicinity of the radar is only illuminated for a very short period per scan. Thus, if the radar features a failsafe inhibition of the transmitter in case of a stop of the antenna movement, the long-term averaging may be applied when estimating the safety distances. However, the transmitter inhibition must comply to certain design standards for safe equipment. A simple sensing of the antenna movement by monitoring the antenna position data provided to the signal processor and a software-controlled interruption of the transmitter trigger does not satisfy the requirements of modern safety standards.

This paper describes a technique for monitoring the antenna movement and inhibition of the radar transmitter which is compliant to the EU Directive 98/37/EC (Machinery Directive), the relevant product safety regulation of the European Union. The technique allows the application of the long-term averaging of the radiated field strengths for the calculation of safety distances.

2. CALCULATION OF SAFETY DISTANCES

RF hazard limits are usually specified by national and international standards in terms of the RF power density level S_L. For the respective power density the safety distance must be calculated beyond which the RF radiation is tolerable. The example calculations presented in this paper are based on the NEXRAD data with a simplified sidelobe envelope specification. The power density limit complies with the German regulation for occupied areas.

Frequency	2750 MHz
Peak Power:	750 kW
Max. RF duty cycle:	0.23%
Gain	45.5 dB
Beam Width @ -3 dB:	0.95 deg
1. Sidelobe	-27 dBc
Sidelobe Envelope $\theta_{1.SL} \leq \theta \leq 40°$	Line from max. of 1. sidelobe to –40 dBc
Sidelobe Envelope $40° \leq \theta$	-40 dBc
Power Density Limit	10 W/m^2 (= 1 mW/cm^2)

Table 1: Relevant NEXRAD Data

2.1. Far-Field Calculation

If far-field conditions are applicable, the safety distance r_{FF} is calculated from:

$$r_{FF}(\theta) = \sqrt{PG(\theta)/4\pi S_L} \qquad \textbf{Eq. 1}$$

$G(\theta)$ represents the gain of the antenna as a function of the elevation angle θ. P is the transmitter power. If the weather radar is operated with typical duty cycles of 0.1% - 0.2% most standards allow the application of the average power.

For the calculation of the safety distance it is useful to apply the sidelobe envelope specification of the antenna. From this specification and from the mainlobe characteristics the complete gain pattern function from 0° to -90° elevation angle can be calculated. The simplified sidelobe envelope specification for the NEXRAD antenna is shown in Fig. 1.

The calculation requires not only the gain and the –3 db beam width but also the bulge width of the main lobe. The bulge width can be taken from measured data or from a calculation based on the antenna aperture illumination function (Sherman, 1970). The combined envelope of mainlobe and sidelobes is then transformed from a $G(\theta)$ function into an x,y-plot by applying the transmitter power and the respective power density limit as shown in Fig. 2.

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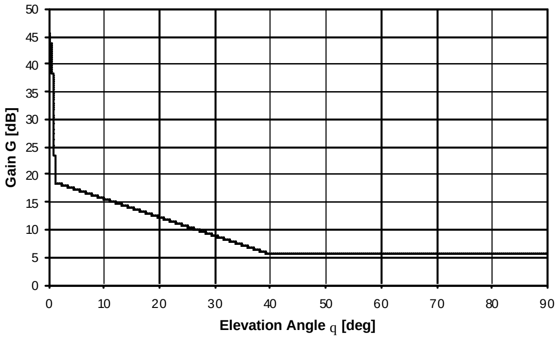

Fig. 1: Mainlobe and Sidelobe Envelope

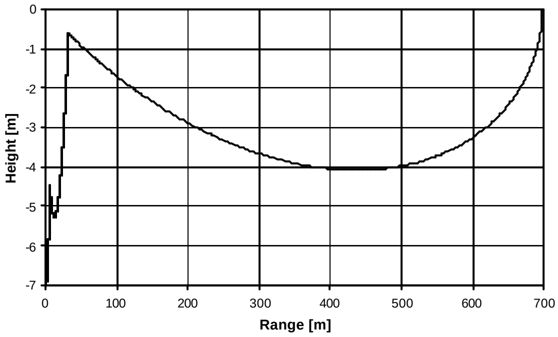

Fig. 2: Envelope as Function of Range and Height

2.2.Near-Field Calculation

In particular for radars with low average power levels the application of far-field conditions gives unrealistic high power density levels for areas close to the antenna, because the radiator is assumed to be a spot with infinite small aperture. The calculation of the near-field components in closed form is very cumbersome, if not impossible. Therefore estimations are required which provide safe figures for the safety distances.

Some standards like the Safety Code 6 of Health Canada do already suggest methods for near-field estimations. Others refer to publications describing suited estimation techniques. The German DIN VDE 0848-1 refers to Heinrich, 1994. In this publication the space in front of the antenna is separated in two spaces as shown in Fig. 3.

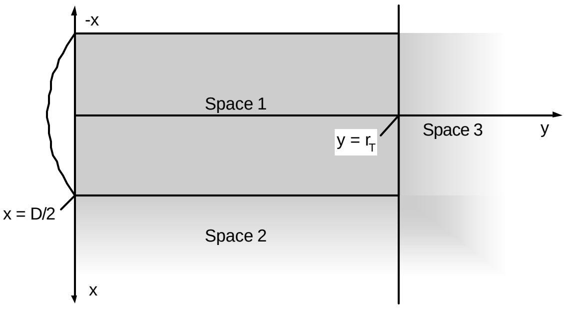

Fig. 3: Space Regions for Power Density Estimation

Within Space 1 the power density is estimated from:

$$S = 4P/A = 16P/\pi D^2 \approx 5.1P/D^2 \qquad \textbf{Eq. 2}$$

The power density in Space 1 is independent of the distance from the antenna. A is the aperture area of the antenna. Depending on the respective limit it is quite possible that the power density estimated by Eq. 2 exceeds the limit, in particular for high power radars with small antennas. For the example considered in this paper, the power density estimation according to Eq. 2 yields 120 W/m ^{2} (12 mW/cm^2) which also exceeds the limit. In this case the safety distance on the beam axis must be calculated from Eq. 1.

The transition from far-field calculation to near-field estimation at range r_T is depending on the antenna diameter D and on the wavelength λ (Heinrich 1994):

$$r_T = 0.4D^2/\lambda \qquad \textbf{Eq. 3}$$

Note that Eq. 3 is not the well-known Fresnel-Fraunhofer range $2D^2/\lambda$ or the Rayleigh range $D^2/2\lambda$. Therefore the expressions "far-field" and "near-field" used in this paper do not comply with standard wording as used in physics. For the given example the transition distance is 267 m.

Note also that for the antennas under consideration the inequality expressed by Eq. 4 is always satisfied:

$$\frac{PG(\theta)}{4\pi r_T^2} \le \frac{16P}{\pi D^2} \qquad \textbf{Eq. 4}$$

In Space 2 the power density decreases with increased distance from the beam axis according to:

$$S = (4P/A)(D/2x)^k \qquad \textbf{Eq. 5}$$

For $20 \le D/\lambda \le 100$ the exponent k is 3. for larger antennas k is 5. From Eq. 5 the safety distance for a specific power density limit can be calculated:

$$x_{NF} = D\Bigg/\left(2\cdot\sqrt[k]{\frac{S_L A}{4P}}\right) \qquad \textbf{Eq. 6}$$

For the example a height of 9.8 m is calculated.

In Space 3 far-field conditions can be applied.

2.3.Calculation Procedure

Before safety distances are calculated, the power density in Space 1 must be checked. If the power density limit specified by the respective safety standard is not exceeded, the definition of a safety distance is not required.

If the limit is exceeded the safety distances must be calculated for the far-field and near-field regions from Eq. 1 and Eq. 6. The result of this calculation for the example system is shown in Fig. 4.

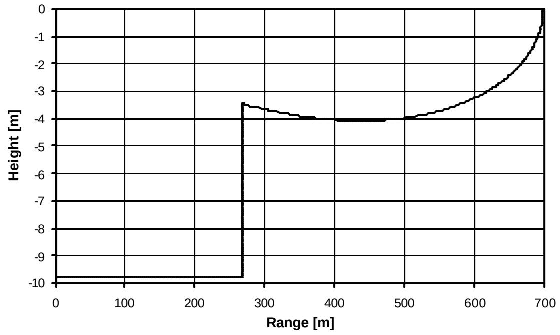

Fig. 4: Safety Distances for the Near- and Far-Field Regions

The transition range r_T determines the height of the safety space for the region close to the antenna. Although Fig. 2 might indicate that the height must not be extended up to r_T, it must be taken into account that the distances in Fig. 2 are calculated from data which are only valid in the far-field. Close to the antenna the sidelobes and in particular the nulls between the sidelobes will not be very pronounced. Therefore the larger distance r_T should be used for safety reasons.

A further simplification is achieved if not the complete mainlobe but only its the bulge is considered. This is shown in Fig. 5.

This simplification allows the specification of all safety distances with only four figures:

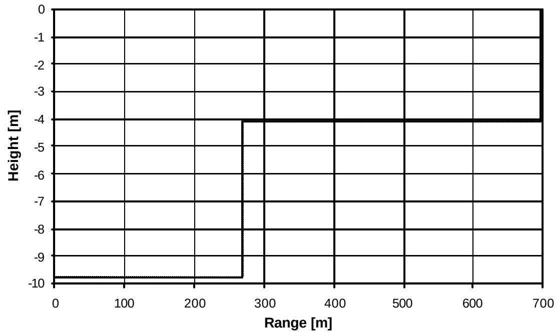

Fig. 5: Simplified Safety Distances for the Near- and Far-Field Regions

1. the safety distance for zero height
2. the transition distance r_T
3. the height for $r > r_T$
4. the height for $r < r_T$

The safety distances for the example were calculated without considering a safety margin. A reasonable way to add a margin is the multiplication of the limit power density by a factor of two. Our experience has shown that the calculation method presented in this paper resembles real values quite well. An additional safety margin would also guarantee that the relatively inaccurate power density meters will never read figures above the limit.

3. REDUCTION OF THE SAFETY DISTANCES

Most safety standards are taking the rotation of the radar antenna into account by averaging the power density level at a fixed place over a long period, typically 6 minutes. If the antenna rotation rate f_{AZ} does not drop below $f_{AZ,min}$ as defined by Eq. 7 an additional duty cycle d_{AZ} which is only depending on the beam width ϕ may be applied for the calculation of safety distances.

$$f_{AZ,min} = 1/T_{av} \qquad \textbf{Eq. 7}$$

$$d_{AZ} = \phi/2\pi \qquad \textbf{Eq. 8}$$

If the averaging period is 6 min, then the minimum rotation rate is 0.17 rpm, a rate which is hardly used by any weather radar. For 1 deg beam width the azimuth duty cycle is 0.16 which would release most weather radars from the definition and enforcement of any safety distances.

However, this is only allowed if it is ensured that the antenna rotation rate never drops below $f_{AZ,min}$ as long as the transmitter is on. The design of the radar control system must consider the fact that this is a safety condition which may affect the health of people. Such conditions are handled in the EU States by the Machinery Directive.

If the condition is controlled by software, this software must comply to IEC 61508 (corresponds to EN 61508) which defines the rules for the design, test and commissioning of software for the control of safety-related functions. The requirements are comparable to the software standards applied for the development of modern airplanes. Because the application of this standard for the radar control software would increase the cost significantly, AMS-Gematronik has chosen a different approach.

In the new METEOR weather radar systems safety-related functions are controlled by a separate control processor, the Safety Programmable Logic Controller (SPLC). The SPLC is certified according the Machinery Directive for the control of safety-related tasks. The required safety level is achieved by a redundant design. Among other functions the SPLC ensures that the antenna rotates if the transmitter is on, should the radar be installed on a site with critical distances to occupied objects. A block diagram of the safe antenna control system is shown in Fig. 6.

Besides the high-precision encoders which measure the antenna angles for the signal processor and the Antenna Control Unit (ACU) for the control the movement of the antenna, each rotation axis feature two additional, redundant encoders for safe rotation control. These encoders are monitored by the SPLC. If the rotation rate drops below a predefined limit or if a malfunction is detected the transmitter trigger is interrupted and the radar control system is informed. For clarity reasons the signal processor functions (angle ingest, transmitter trigger) are not shown in Fig. 6.

It is of course possible to operate the transmitter with a fixed antenna. This can be accomplished by pointing the antenna at 90° elevation or by programming the

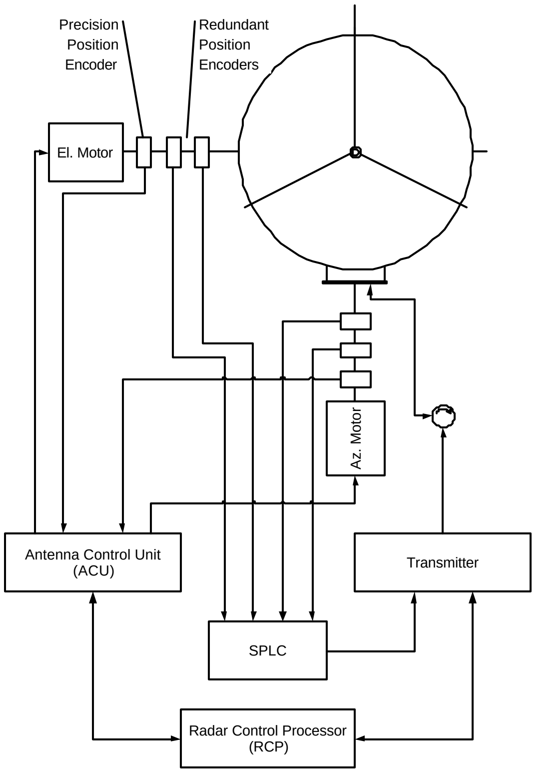

Fig. 6: Safe Antenna Control System

SPLC for certain azimuth angles which are free of critical obstacles.

4.CONCLUSIONS

The method presented in this paper allows an easy yet safe estimation of radar safety distances with respect to RF radiation limits. A safe control system was presented which eliminates the need for considering dafety distances when selecting a radar site for nearly any weather radar system.

5. REFERENCES

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