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Numerical Simulations of Environmental Distortions by Scattering of Objects for the Radar - SSR and Flat Roofs, RCS and Windturbines

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Abstract – **Two cases of potential distortions of radar by environmental objects are introduced and theoretically and numerically analyzed.**

1. **Metallic flat roofs and the SSR/MSSR with regard to false interrogations and monopulse angle error.**
2. **Windturbines and its representation by the radar cross section RCS for the radar and in particular for the weather radar.**

It is outlined that the flat roofs of buildings are acceptable without scattering fences and that the RCS is not applicable for objects on the ground such as for the windturbines.

Index Terms – **Building, distortions, radar, RCS, roof, SSR, weather, windturbines**

I. INTRODUCTION

The radar sstems work according to its intended performance in the absence of distortions. These distortions are often caused by objects which are located relatively close to the radar. These objects may be existing buildings in case of a relocated radar or newly built or planned objects such as windturbines in some distance to the ATC, military or weather radar.

The operator wants to know in which way these objects will harm the performance of the radar. The radar must meet its intended tasks under the impact of the objects. On the other hand “no distortions” or “no risk” is technically also unfeasible. Often it is not unique and not obvious if the “effect” is a distortion or a matter of dis-comfort and not a real threat for the radar. Natural objects such as the flat ground or hills or mountains affect also the performance of the radar. Depending on the radar system the countermeasures are very much different. This paper discusses 2 radar types with one “distorting scenario” each and its analysis. This is for the SSR/MSSR and the metallic flat roofs of nearby buildings and some related aspects and the analysis of the effects of windturbines WT on radar, in particular on the weather radar WR.

II. THE SSR/MSSR AND METALLIC FLAT ROOFS

Modern large buildings such as maintenance hangars for the wide body aircraft (B747, A380) are built on airports relatively close to the higher ATC-radar (primary radar, secondary radar SSR/MSSR). Reflections from buildings can distort in particular the SSR/MSSR (Fig. 1) by creating false interrogations of the aircraft transponder. By that false tracks can be created having the confusing identical code (Fig. 1). Powerful so-called anti-multipath algorithms exist which attenuate the multipath reflections virtually by a certain figure (e.g. 10dB). However, situations exist where the reflections must be reduced by appropriate measures [1],[2]. Typically these large buildings have almost flat metallic roofs creating virtually strong reflections (Fig. 2). The theoretical analysis of these reflections for realistic scenarios shows that

1. The spatial azimuthal direction is the same compared to the direct signal.
2. The amplitude of these roof reflections is smaller than the direct signal and also smaller than the normal total ground reflections.
3. The phase is somewhat advanced compared with the normal reflection from the flat ground, but having a similar phase than the ground reflected signal.
4. The arrival of time is delayed compared to the direct signal and somewhat advanced compared to the normal ground reflected signal. A simple geometrical calculus shows that the time difference is very small compared to the length of the SSR-pulse. By that, this potential impact is negligible.

A flat ground does not affect the SSR/MSSR system as is well known [3] except the elevation lobing. It can be easily estimated that the first fact indicates generally negligible effects of the SSR/MSSR-performance, because the general effects are similar to the effects of a flat ground. The flat roof can be treated as just an elevated local flat ground. This conclusion is applicable for the non-appearance of false interrogations as well as for the non-affected monopulse angle accuracy. Which other effects can be expected? The 2nd and 3rd listed facts affect the elevation pattern of the radar antenna on top of the “normal ground effect”. Fig. 4 shows a numerical example of such a pattern simulation. It can be clearly seen that the effects of this very close and large roof are generally small compared to the flat ground. Close to the ground or horizon where the signal strength is weaker, the flat ground effect is much larger than the effect of the flat roof. These natural amplitude variations of the antenna pattern caused by the ground do not create system problems, except limiting the range in the minima. These natural amplitude variations appear in the sum as well as in the difference pattern of MSSR yielding a constant monopulse ratio. Amplitude variations in itself are not a distortion and are not directly related to the monopulse angle accuracy. By all that, in conclusion no effects should be expected by metallic flat roofs in normal scenarios. “Normal” means that the radar antenna is sufficiently higher. By that diffraction components at the roof-rims and roof-corners are negligible and a direct shadowing does not occur. However, attempts are known to suppress the roof reflections by scattering fences on top of the roof (Fig. 3), although not necessary. Simple geometrical optics ideas may suggest that the common “attika” at the roof rim or some kind of scattering fences prevent the roof reflections by shadowing. It will be shown by numerical examples that the scattering fences must be electrically large if they should meet their assigned task of shadowing, again although not necessary. Electrically large metallic fences mean a height of about 10λ minimum, i.e. about 3m for the SSR. If the fences are too low, the waves simply flow around the fence and the fields recover fast. No effective shadowing is encountered, but only in the direct back of the small fences. But, if they are effective and large, they constitute a distorting object. Sometimes lattice and wire type support structures are on top of flat metallic roofs. These structures can be treated as diffuse scatterers working on the flat roof reflections or as approximate scattering fences. In any case no measures or modifications are necessary as a rule of thumb. By that, conversions of the support structures to real scattering fences or additional scattering fences are not necessary also. Features and more numerical examples of scattering fences are shown on the conference itself.

III. OBJECTS ON THE GROUND AND RADAR; RCS

An actual widely discussed example of a distorting object is the case of windturbines WT and radar, in particular the weather radar WR (Fig. 5). The typical WR [7] has a pencil beam of 1° beam width. The WR is sampling the space by periodic scanning. The lowest elevation beam position is 0° to about 0.7° at the horizon. By that the ground effects for these low elevations create the lobing of the elevation pattern as a normal feature for a WR. The WT are illuminated too in these positions and superpose a bit in small volumes only. For a modern typical WT, the nacelle may be in a height of 80m. This results in an elevation angle of about 0.6° assuming a distance of the WT of 5000m and a local height of 30m.

It is common to characterize the objects for the radar by the RCS (σ, radar cross section; mono-static, bi-static).

$$\sigma_{pq} = \lim_{R\to\infty}\left[4\pi R^2 \frac{\left|E_p^s\right|^2}{\left|E_q^i\right|^2}\right] \qquad (1)$$

The general definition of the RCS (1) [4] assumes an asymptotic infinite distance. That implies the plane wave excitation or a real far-field approximation [4],[5],[6],[8] . The plane wave is characterized by a constant amplitude and by a linearly progressing phase across the object. The WT are naturally installed on the ground and by that the ground interactions have to be taken into account for the lowest beam positions which are relevant for the WT only.

The mono-static RCS of a WT in free space is extremely structured and lobed due to the electrically large size of the WT. The RCS is also very sensitive for the spatial direction. By that again, strictly speaking the RCS is different for the direct signal and the ground reflected signal also. Large amplitudes in narrow peaks (“flashes”) and interference are superposing an average RCS generated by the conical frequently metallic shaft. The RCS of lattice type shafts is typically much lower.

The effects of the ground are twofold, for the excitation caused by the radar at the WT (Fig. 6) and for the echo response scattered by the WT (Fig. 7) at the location of the WR. The WR has some height above ground and the WT effectively also (Fig. 5). By that, two sources of fundamental errors occur if the RCS-scheme is applied to the WR/WT-case, namely the non-existence of the plane waves for the validity of the RCS and the distorted lobing field amplitude in the scattered response at the location of the WR (Fig. 5). The amount of error is unpredictable and has to be analyzed by appropriate tools and numerical methods in a deterministic sense case by case. Further numerical results will be shown on the conference itself.

A further interesting technical issue of the WT with regard to the pulse-Doppler-WR and the RCS is that of the rotating blades. The blades may rotate up to 22/min. By that their radial velocity may be up to 300km/h at the tips and a high Doppler-shifted frequency may be created by the rotation (up to about 3kHz for the C-band WR). Typical WR measure a maximum wind/cloud speed uniquely up to about 110km/h having a typical real resolution of about 1m/sec. The amplitude of the Doppler shifted signals depends on many factors such as the orientation of the WT and the back scattering properties of the blades. However, in any case the Doppler-shifted back-scattered signal represents a continuous spectrum and contains positive and negative Doppler shifts. By that again, the simple stationary monostatic RCS of the blades is not representative for the rotating blades. In fact, the RCS is distributed and much reduced by the Doppler-spectrum. One can define a RCS-frequency-function in dBsm/Hz. One can understand that easily since only a small subpart of the blades creates the related Doppler frequency and not the total blade. Only in case of the non-rotating stationary blades the total blades contribute to the 0Hz-signals which are suppressed by the MTI/MTD mechanism by 40dB minimum in case of modern radar.

IV. CONCLUSION

Two radar problem areas have been discussed theoretically and by numerical results.

First, it has been outlined that a flat metallic roof of a building does not create system problems for the higher SSR and scattering fences are not necessary on top of flat roofs. Lattice type support structures on the flat roof can be treated as approximative fences and need not to be treated.

Second, the simple stationary theory of radar cross section RCS is strictly speaking not applicable for objects on the ground such as windturbines with regard to radar in general and also not for the weather radar. The RCS of the total stationary blades is not applicable for the Doppler-evaluation. The error made by a worst-worst-case analysis (RCS, Doppler) is unpredictable and can be very large. By that, the RCS does not seem to be adequate for the definition of safeguarding distances for windturbines related to radar. A deterministic state-of-the-art scattering analysis has to be carried out which takes into account the 3D-model of the windturbines and the relevant electrical features and the geometry of the radar in relation to the windturbine.

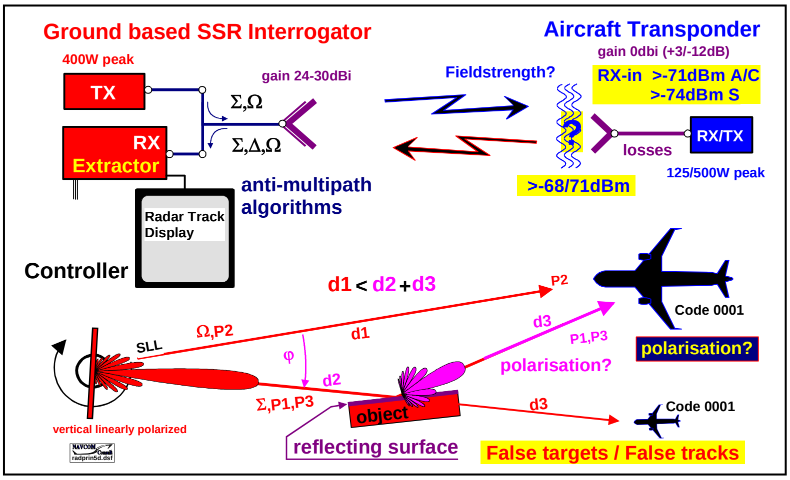


Fig. 1: SSR/MSSR-concept and the mechanism of multipath generated false interrogations

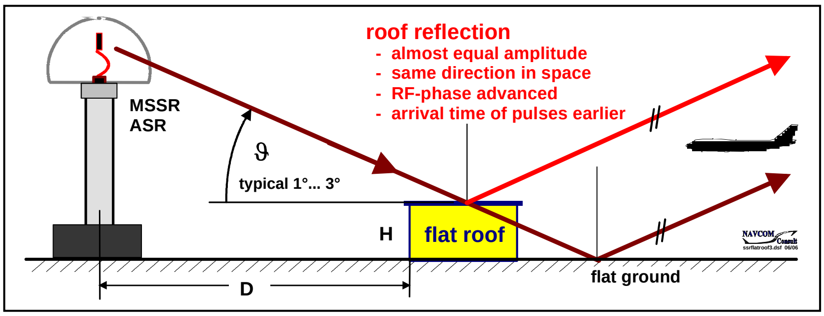


Fig. 2: Flat roof scenario for ASR/MSSR and the basic theoretical effects

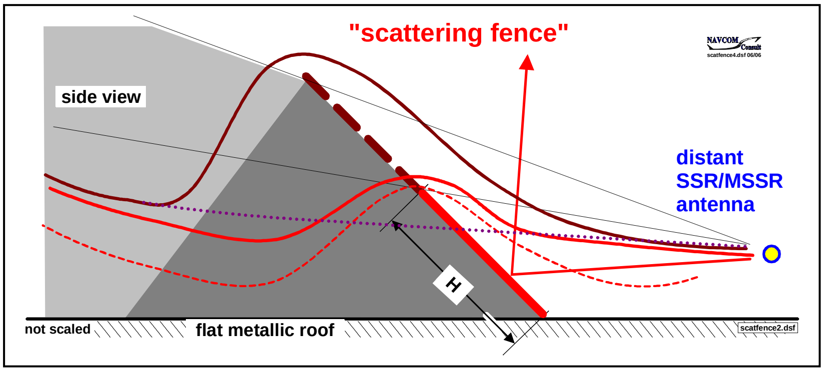


Fig. 3: Schematic of scattering fences; shadow and "flow around"

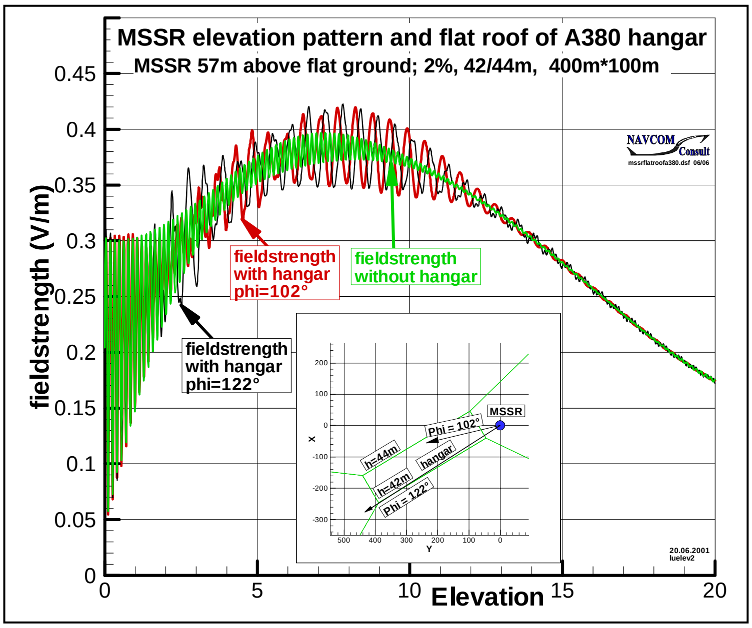


Fig. 4: Effects of the ground on the elevation pattern of the MSSR-antenna; additional effects by the flat metallic roof of an A380-hangar. The effects of the flat roof are negligible at the tentatively range critical low elevation angles;
Application of GTD/UTD

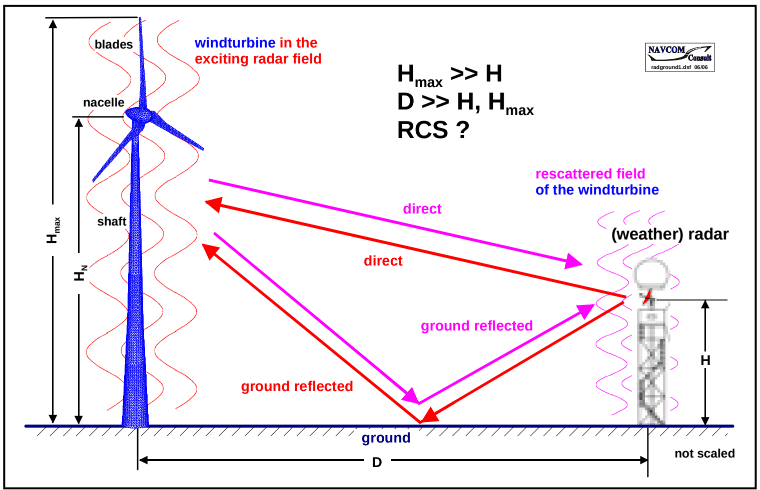
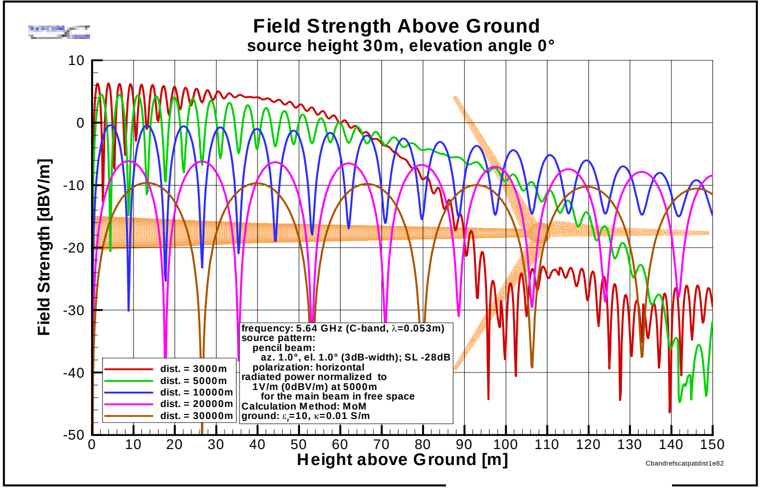
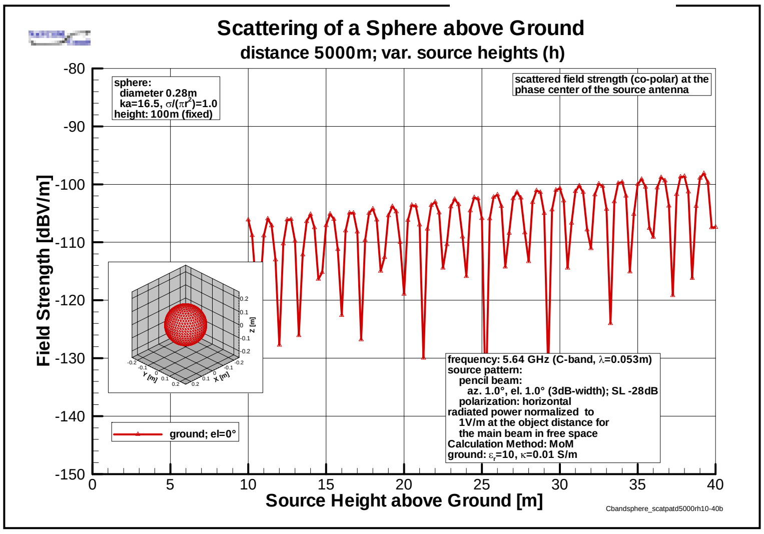


Fig. 5: Schematic of the windturbine in the radiation field of a weather radar above ground; direct and ground reflected components occur for both directions, in the forward as well as in the backward direction; the exciting field of the radar at the windturbine as well as the re-scattered field at the location of the radar are interfering fields of the direct and the ground reflected fields



frequency: 5.64 GHz (C-band, λ=0.053m)
source pattern:
pencil beam:
az. 1.0°, el. 1.0° (3dB-width); SL -28dB
polarization: horizontal
radiated power normalized to
1V/m (0dBV/m) at 5000m
for the main beam in free space
Calculation Method: MoM
ground: ε_r=10, κ=0.01 S/m

Fig. 6: Numerically calculated exciting field at the location of the metallic windturbine for different distances of the C-band weather radar (3,5,10,20,30km); flat ground/earth assumed; horizontal elevation of the radar beam; in the shorter distances of 3km and 6km only a part of the windturbine is illuminated;
Application of an improved Physical Optics method (IPO) for a metallic 3D-triangular patch model



sphere:
diameter 0.28m
ka=16.5, $\sigma/(\pi r^2)$=1.0
height: 100m (fixed)

scattered field strength (co-polar) at the phase center of the source antenna

frequency: 5.64 GHz (C-band, λ=0.053m)
source pattern:
pencil beam:
az. 1.0°, el. 1.0° (3dB-width); SL -28dB
polarization: horizontal
radiated power normalized to
1V/m at the object distance for
the main beam in free space
Calculation Method: MoM
ground: ε_r=10, κ=0.01 S/m

Fig. 7: Numerically calculated re-scattered field of a metallic sphere (height 100m above flat ground, distance 5km to weather radar , diameter 28cm) at the location of the C-band weather radar having a variable height between 10m and 40m;
Application of the rigorous MoM (method of moment)

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