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Numerical Analysis of the effects by scattering from objects on ATC-radar and various methods for its reduction - Theory, results

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Abstract: *The necessity of the reduction of the reflections from objects is outlines for ATC radar, in particular for the secondary radar. Principal measures and real measures are discussed. Some of these do not work as proposed and others are effective and consistent with physical principles.*

Introduction

This paper is related mainly to ATC-radar which is located often on airports or close to airports. More potentially distorting objects in quantity, larger in size and often close to the radar are planned to be built coping the increasing air traffic.
The radar antenna scattering analysis is often the decisive and integral part of the practical system analysis. The integrated analysis methods can be "simple estimates", crude approximate numerical methods or recommended state-of-the-art advanced numerical methods.
By that the accuracy and reliability of the system results depend on the results of the applied numerical methods. Modern systems analysis has often important technical, economical and safety aspects for aviation applications, i.e. navigation and radar fields. New buildings (e.g. the newly planned A380 hangar or new terminals) have to be approved in advance and its effects on the existing systems have to be analyzed/simulated reliably. All numerical methods have limitations and a certain set of application-rules have to be applied. If the user does not follow the rules he will get nice (colored) graphics and numbers, but which may be in parts or completely wrong.
Several examples of methods to reduce the reflections/scattering are described theoretically and numerically. There are methods to reduce the reflections which work as proposed and others which do not work as proposed. The latter are unnecessary and a waste of resources, such as scattering fences on flat roofs (Fig. 1, 2), chess type surfaces (Fig. 3; so-called “interferences absorbers”) and “wire type glass absorbers” (Fig. 5) . The main problem of these “methods” is that they contradict the fundamental law of the conservation of energy.
On the other hand methods are discussed which work as designed, such as real absorbers which convert the electromagnetic energy into heat or surfaces which act as diffuse reflectors (Fig. 4).

Requirements for the reduction of reflections for SSR radar systems

The SSR transponder on board of the aircraft will be interrogated if the minimum threshold level MTL is exceeded. The MTL is specified by ICAO Annex 10 Vol. IV for a defined reply-to-interrogation ratio of 90%, i.e. for Mode S -74dBm±3dB and for Mode A/C “nominally -71dBm with limits between -69dBm and -77dbM. This value can be interpreted that the actual Mode-S-transponder responds to an input level of -74dBm at its antenna terminal to 90% of the valid interrogations or also that 90% of the transponders will answer for an MTL of -74dBm. This assumes that the transponders are adjusted in such a way that the nominal MTL is set, i.e. -71dBm for Mode A/C and -74dBm for Mode S. However it is also defined that maximum 10% of the Mode-S-transponders answer to a MTL-level of -81dBm. If somebody wants to have no answers at all with 100% probability a much lower MTL-level has to be considered, may be -87dBm. These MTL are defined at the antenna input terminal of the transponders. Losses of the cabling and an average gain of the aircraft antenna have to be applied. It is a widely common international practice to use a total loss of 3dB yielding an

"effective MTL" of -71dBm for Mode S and -68dBm for Mode A/C operation. In field simulations, the amplitudes of the fields outside of the aircraft will be calculated. These MTL-levels do not take into account further signal processing advantages for multipath suppression in the modern SSR ground interrogators.
The suppression of the potential "false interrogations" of the SSR-transponder on board of the aircraft requires the determination of the actual field amplitude outside the aircraft which corresponds with the mentioned "effective MTL". "False interrogations" may be generated by reflections from objects. By that the determination of the reflected or scattered fields has to be calculated in the coverage volume which is typically defined by the MRVA (minimum radar vectoring altitude). If the false interrogation level exceeds the effective MTL, this exceeding level has to be reduced by adequate means. These means are reliable and "state-of-

Discussion of potential measures at the object

The first task is to verify by a reliable "state-of-the-art"-analysis that an improvement is necessary and justified. The achieved improvement may be difficult to verify because the proposed measure have to be realized before a reliable verification is possible in the field. The general target is to reduce the reflections/scattering of the object. However, the question arises if this is possible for all directions and all frequencies to be considered. The MSSR has of course only one single frequency, but there are other radars and also other radio navigation systems in operation on airports which should not be harmed by the intended measure for the MSSR-radar. The following general principles exist

1. ***absorption*** of the illuminating wave by transforming the energy into heat. This is a real absorption and meets the general physical law of the "conservation of energy".
   Problems and aspects: bandwidth and direction of incidence. A broadband absorption and also noticable effects for almost oblique incidence are difficult/impossible to achieve.
2. ***destructive interference (Fig. 3)***, i.e. high cancellation of a certain (reflected/diffracted) signal in a certain direction. This is sufficiently possible only in one spatial direction. The socalled "chess type surface" is an example of this kind of measure. One can find papers where this type is called "interference absorber". It is obvious that that measure contradicts the fundamental physical law of "conservation of energy".
3. ***Conversion of the polarisation (Fig. 5).*** There are attempts to design measures like a polarizer. Measuring just the reduced crosspolar components is not an operational solution in the real aviation environment where the aircraft fly bends and escape maneouvers.
4. ***diffuse reflection and diffraction (Fig. 4)*** , i.e. reducing the scattering directivity/gain in a wider angular range by introducing random phase errors. By that it is kind of "destructive interference". The design needs systematic random analysis and optimizations. This methods works up to sufficient mid-level reductions of the reflections, but a very high suppression is effectively not possible. The important advantage is that it works for higher frequencies than the design frequencies and in a wider angular range.
5. ***redirection of the incoming wave*** into spatial directions which do not harm the radar-system. The question is if these directions at all exist for the particular radar location and if these harmless directions are spatially large enough despite the real scattering pattern.

Summary

Methods and measures to reduce the reflection from surfaces have been discussed for the SSR and classified as partially "working" and partially "not working as intended and proposed". The physical background has been outlined mainly based on the fundamental law of the conservation of energy.

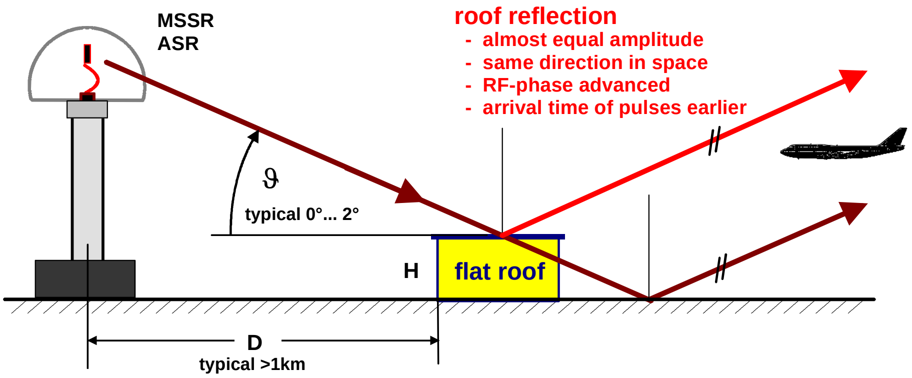

Fig. 1: SSR/MSSR, Schematic of reflections at flat metallic roofs above ground

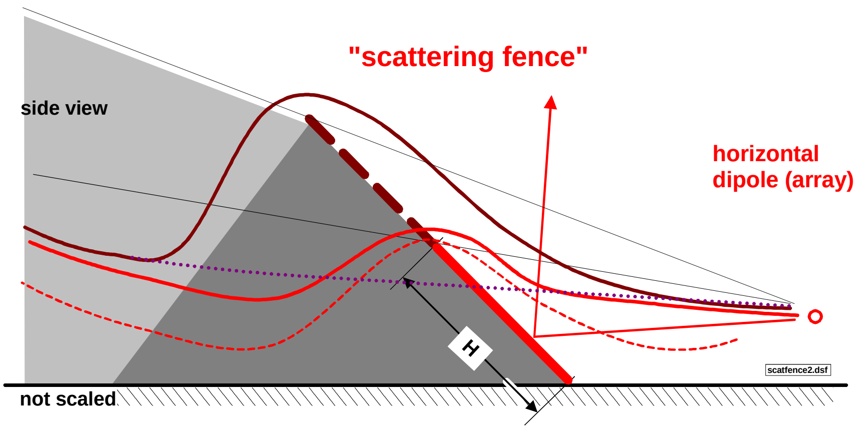

Fig. 2: Schematic of a scattering fence above ground or above a flat roof

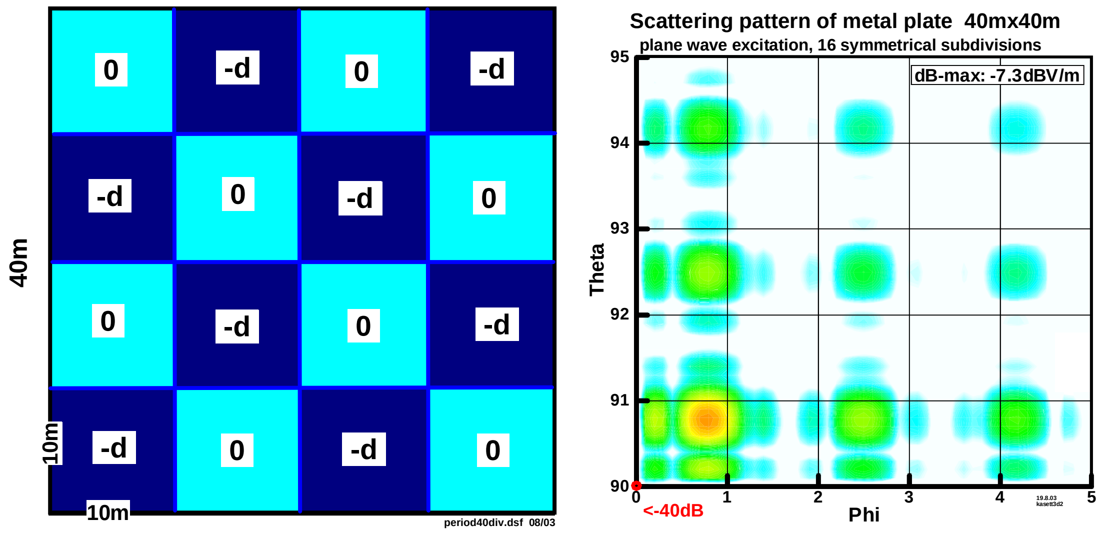

Fig. 3: Schematic, numerical results and example of a periodic scattering structure of very limited effects of about 7dB max instead of >20dB.

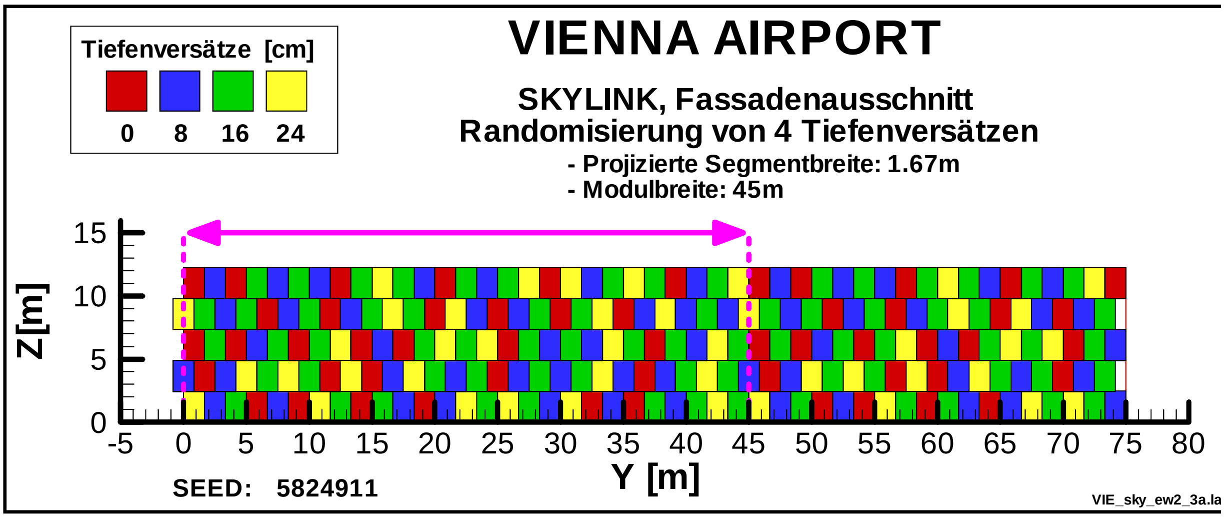

Fig. 4: Randomized surface creating a diffuse reflection with much less maximum amplitudes

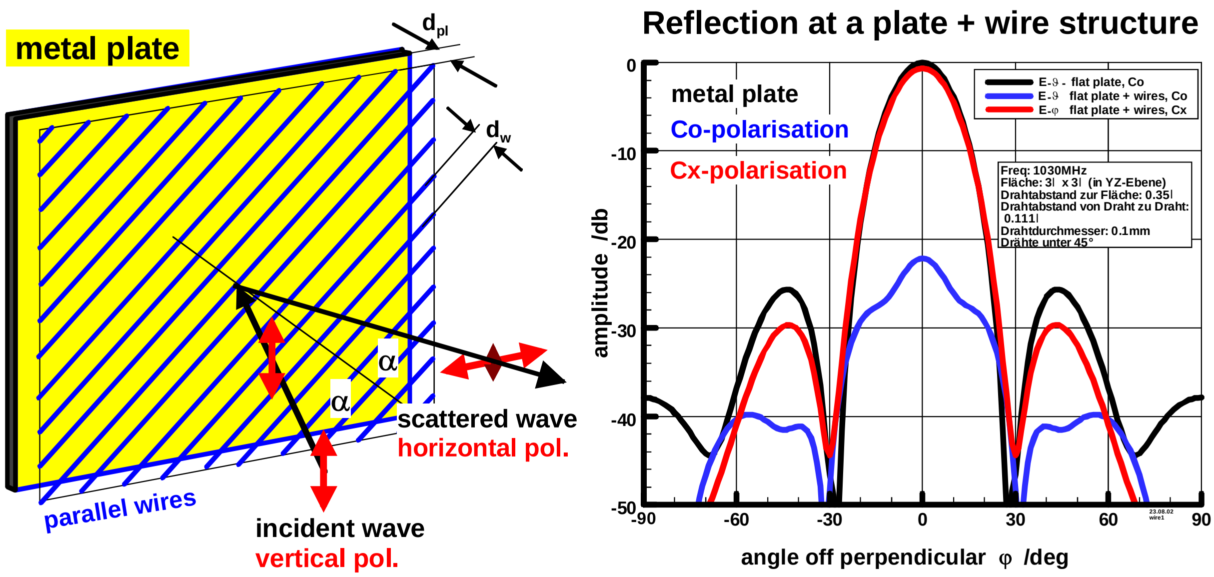

Fig. 5: Layer structure proposed to work as an absorber; Polarizer of metal plate and inclined wires; left: schematic structure; right: copolar and cross-polar scattering

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