Attenuation properties of electrically large periodic structures applying FEM

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***Abstract*—Avoiding electromagnetic field contamination of large rooms is a very cumbersome and expensive task, especially when a widespread frequency range has to be considered. Often, windows serve as vents. This implies the use of absorbing structures with electrically large feedthroughs at a certain mechanical robustness. In this paper the attention has been drawn to metallic, periodic structures like arrays of rectangular waveguides. Electromagnetic waves at different incident angles strike the structure whereas the influence of its thickness will be varied, as well. The prescription of the attenuation properties will be given. All results will be achieved with the aid of finite element computations.**

I. Introduction

In many real life situations large rooms of more or less perfect cleanliness of electromagnetic fields are required, eg. electron microscopy laboratories. Perfectly metallic enclosures often can not be put into practize due to practical constraints like the integration of vents or voluminous wall ducts. At such surfaces the use of metallic wave guides assembled to a periodic structure may achieve both, a required shielding effect as well as a sufficient air flow through it. An idea of such a basic structure is illustrated in Fig. 1. In the shown case quadratic wave guide tubes of a distinct length are stacked and serve for the requested structure.

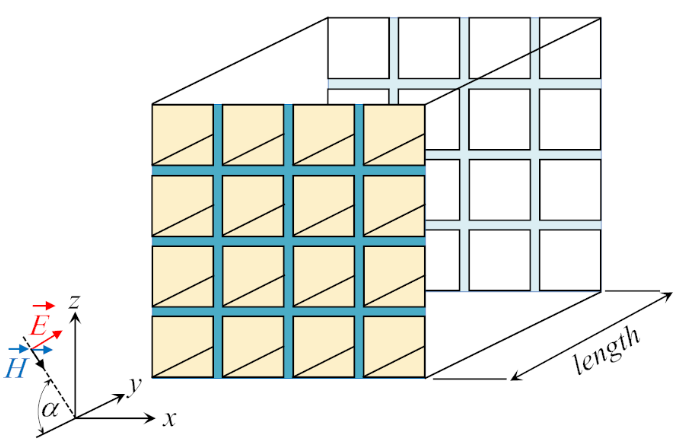

Fig. 1. Basic arrangement, impinging plane wave indicated at an incident angle α, variable thickness.

Obviously, the fill-up of a window with such a structure ends in a length (indicated in Fig. 1) of tens of centimetres. Hence the structure becomes electrically long in terms of free space wave lengths for the GHz-frequency range. This and the high conductivity of the material (metallic walls) is a real drawback while evaluating its attenuation behaviour numerically. Any simulation operating with material homogenization, as pointed out, eg. in [1], [2] will fail. Neither the treatment as a frequency selective surface [3] will succed. This necessitates the computation of fully 3-D periodic structured models.

II. Modeling and field formulation

We have to face a wave propagation problem at the coexistance of highly conducting materials. Thereby, the problem of modeling a non-perpendicularly impinging plane wave arises which is outlined in the basic arrangement in Fig. 1. The use of the well known $\vec{A}v$ FEM-formulation (eg. [4]) will be of best advantage. Therein, the electric field intensity is expressed by

$$\vec{E} = -j\omega\vec{A} - \nabla v. \tag{1}$$

First of all, surfaces with plane wave prescriptions should be considered as equipotential surfaces. Hence, the electric scalar v can be set to zero and the gradient term in (1) vanishes. Hereafter, bearing the definition equation of $\vec{A}$ to be

$$\vec{B} = curl\vec{A} \tag{2}$$

and its representation with edge basis functions in mind, an impressed electric field $\vec{E}_0$ can be constructed in terms of $\vec{N}_k$ [5]

$$\vec{E_0} = \sum_{k=1}^{e} e_k \vec{N}_k. \tag{3}$$

Herein, e is the number of edges, $\vec{N}_k$ represents the k-th edge basis function. Now, the values e_k can be obtained by the line integrals along the $k-th$ edge of the impinging electromagnetic wave

$$e_k = \int_k \vec{E}_0\, e^{j\omega(t-\frac{\vec{r}\cdot\vec{e}}{c})} \cdot d\vec{l}. \tag{4}$$

Finally, as a consequence of (1) the values e_k may be subdivided by $(-j\omega)$ and the values obtained can be treated as inhomogenous Dirichlet boundary conditions.

III. Numerical investigations

For a first series of computations one single tube of the arrangment shown in Fig.1 has been modeled, only. The frequency range of interest is between $1\,GHz$ and $18\,GHz$. The geometry of the aluminum tube is shown in Fig. 2.

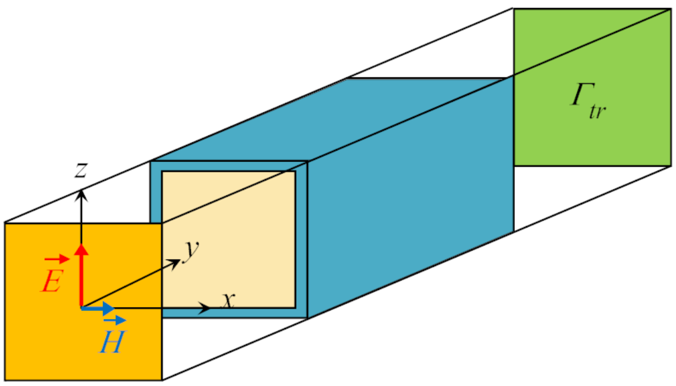

Fig. 2. Single wave guide, size = $12 \times 12\,mm$, wall thickness $1\,mm$.

Along the front facet the plane wave excitation has been modeled. At the back end (Γ_{tr}) the FE-mesh has been truncated with first order impedance boundary conditions. At first, investigations with plane waves impinging perpendicularly to the structure have been done. For the set of computations the cross section has been kept constant whilst the length of the aluminum tube has been varied. As a result the attenuation factor, defined by

$$a_t\,|_{dB} = 20\,\log \frac{|\hat{E}_{in}|}{|\hat{E}_{out}|} \quad (5)$$

has been postprocessed. Therein, $\hat{E}_{in}$ and $\hat{E}_{out}$ represent the maximal magnitudes of $\vec{E}$ at the entrance and at the exit port. At a frequency intervall of $3\,GHz$ the whole frequency range has been swept over.

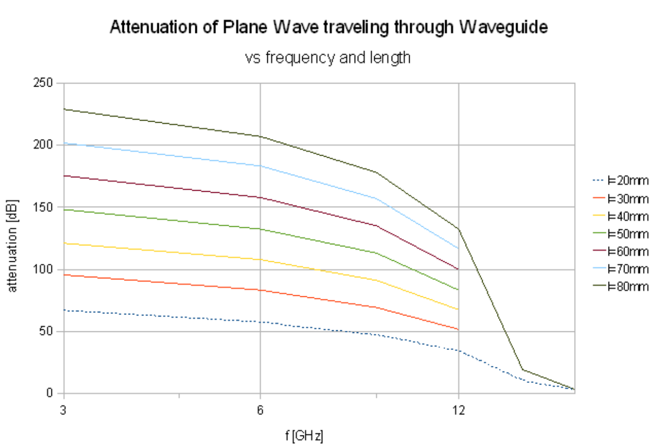

Fig. 3. Attenuation factor at distinct lengths and frequencies.

As can be seen, frequencies above $15\,GHz$ will pass the wave guide without any remarkable attenuation.

At frequencies below this cut off point, the attenuation of the waves not only depend on the cross section, but on the length of the tube, too. Considering a fixed frequency, e.g. $6\,GHz$, one can notice a non-linear decay of the attenuation factor with respect to the length of the tube.

Close to the cut-off frequency, an incoming wave will be attenuated evanescently. Depending on the length of the wave guide, a residual quota of the attenuated fields can remain which causes further wave propagation after the output port of the tube. Hence, a sufficient screening behavior may not be given. This behavior depends strongly on the incident angle of the plane wave. The examinations of this behavior will be reported in the full paper in detail.

The up to now investigations enforce the assumption that stacked arrays of waveguides suffer from a decrease of the shielding effectiveness compared to the attenuation accomplished by a single tube. This, as well is matter of the continuous investigations.

IV. Conclusion

The paper describes a procedure for computing the attenuation behavior of periodical structures made of high conductive material. Due to mechanical reasons the length of such structures will become electrically long in terms of wavelengths. Hence, no homogenization procedure can be applied to model the structure conventiently. A method has been proposed how to excite a problem with skewed impinging plane waves while using a vector potential edge presentation in the finite element formulation. For different length of the screening scructure and for variant incident angles the attenuation behavior will be discussed.

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