DISSIPATION IN THICK FREQUENCY SELECTIVE STRUCTURES

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ABSTRACT

Dissipation in Frequency Selective Structures (FSS) of aperture/slot type is studied. The dissipation in an FSS is due to losses in the dielectric material, and losses due to finite conductivity in the metallic plate. The dissipation in the dielectric medium is modeled by the complex permittivity. The dissipation on the metallic structure arises both on the plane metallic surface and on the walls of the apertures. The attenuation and the power losses are calculated for a number of different FSS, and based on these results the performance of an FSS with losses is discussed.

INTRODUCTION

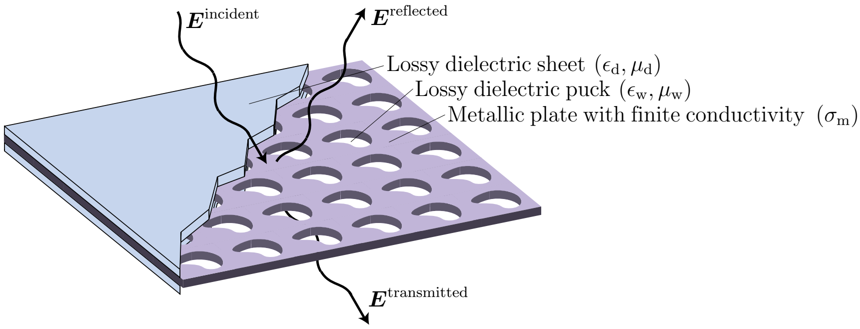

Fig. 1. A Thick Frequency Selective Structure (FSS).

The presence of dissipation in the dielectric medium and the metallic surfaces in an FSS modifies the usual description of scattering by an FSS. This modification takes the form of a complex rather than an real propagation constant, and by introduction of a surface resistance. The transmitted power is approximately given by

$$P_{\text{trans}} = P_{\text{inc}} t_{\text{dl}} t_{\text{dw}} t_{\text{c}} L_{\text{f}}, \tag{1}$$

where t_{dl} is the transmittance due to dissipation in the dielectric layers, t_{dw} is the transmittance due to dissipation in the dielectric waveguide puck , t_{c} is the transmittance due to finite conductivity in the walls of the waveguide, and L_{f} is the loss factor due to finite conductivity in the plane metallic surface. The transmissivities and the loss factor can with good accuracy be determined separately. The transmissivities due to dissipation in the dielectric medium, t_{dl} and t_{dw}, are determined by assuming infinite conductivity for the metallic surfaces, and the transmittance due to finite conductivity in the walls of the waveguide t_{c} and the loss factor due to finite conductivity in metallic medium L_{f} is determined by assuming lossless dielectric medium.

GEOMETRY AND METHOD

The geometry of a simple FSS, that consists of a perforated conducting plate sandwiched between two dielectric slabs, is depicted in Fig. 1. The screen can have an arbitrary number of aperture layers and dielectric layers. An aperture layer consists of an electrically conducting plate perforated with a periodic array of apertures. The apertures are treated as waveguides, can be filled with a dielectric material, and can have arbitrary cross-section.

The method for analyzing the FSS is based on a general mode-matching technique. The FSS is divided into a number of boundaries and uniform layers. The electric and magnetic fields outside the screen and inside the dielectric layers are expanded in tangential plane waves, Floquet modes. The tangential fields inside the aperture layers, are expanded in

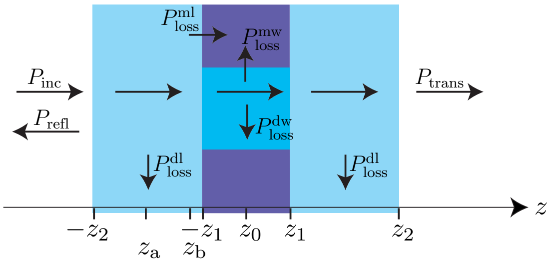

Fig. 2. Power flow through a FSS.

waveguide modes obtained by the Finite Element Method (FEM). The tangential electric and magnetic fields are matched by the boundary conditions at every boundary between uniform sections of the structure, in order to obtain a scattering matrix. For every layer a propagation matrix is calculated. These scattering matrices are cascade coupled to form an overall scattering matrix for the complete FSS. The mode coefficients and fields can be found at every boundary and inside every layer. Extensive discussions on the geometry and the method can be found in [1, 2].

In all examples in the paper, the incident field is a TE-polarized plane wave at normal incidence, that impinges from the left side. More general polarization and direction of incidence are possible, but not shown in this paper. The losses are calculated at the frequency with maximum transmission. In all numerical examples the metallic screen is made of copper.

POWER PROPAGATION

The conservation of power is satisfied, and for the FSS it yields that, the incident power is equal to the sum of the reflected, transmitted, and dissipated power, see Fig. 2,

$$P_{\rm inc} = P_{\rm refl} + P_{\rm trans} + P_{\rm diss}, \tag{2}$$

The dissipated power is decomposed in four different parts

$$P_{\rm diss} = P_{\rm loss}^{\rm dl} + P_{\rm loss}^{\rm dw} + P_{\rm loss}^{\rm ml} + P_{\rm loss}^{\rm mw}, \tag{3}$$

and $P_{\rm loss}^{\rm dl}$ is the power loss in the dielectric layer, $P_{\rm loss}^{\rm dw}$ is the power loss in the dielectric waveguide puck, $P_{\rm loss}^{\rm ml}$ is the power loss in the plane metallic surfaces, and $P_{\rm loss}^{\rm mw}$ is the power loss in the walls of the waveguide. The power flow through an FSS is illustrated in Fig. 3. The structure in the example consists of a hexagonal FSS imbedded in two dielectric layers, as in Fig. 1.

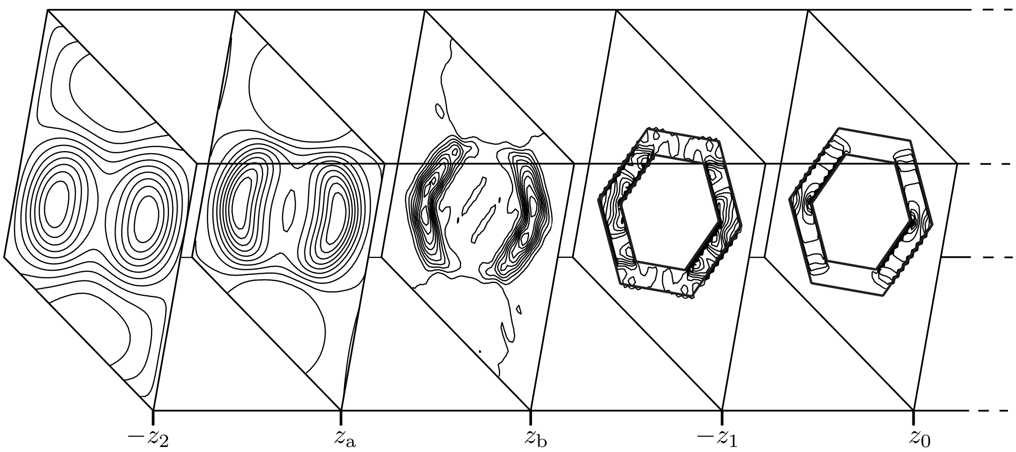

Fig. 3. Power flow density for a symmetric hexagonal FSS, *cf.*, Fig. 2.

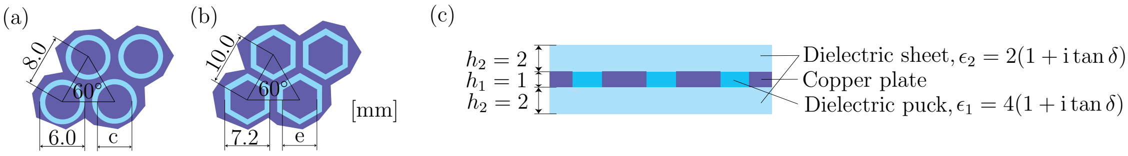

Fig. 4. Two examples of FSS patterns; (a) annular FSS, (b) hexagonal FSS. In (c) the vertical cross-section of an FSS is depicted. Annular 1 has $c = 5.0\,\mathrm{mm}$, while annular 2 has $c = 4.0\,\mathrm{mm}$. The hexagonal FSS has $e = 5.2\,\mathrm{mm}$.

Table 1. Losses in three different FSS.

P_{loss} [dB]			Annular 1	Annular 2	Hexagonal
Losses in the dielectric medium	In the sheets	In the pucks			
	$\tan\delta = 0$	$\tan\delta = 0$	0	0	0
		$\tan\delta = 0.01$	0.40	0.24	0.35
		$\tan\delta = 0.1$	3.27	2.08	2.94
	$\tan\delta = 0.01$	$\tan\delta = 0$	0.20	0.17	0.23
		$\tan\delta = 0.01$	0.58	0.40	0.56
		$\tan\delta = 0.1$	3.41	2.21	3.10
	$\tan\delta = 0.1$	$\tan\delta = 0$	1.75	1.57	2.00
		$\tan\delta = 0.01$	2.08	1.76	2.28
		$\tan\delta = 0.1$	4.54	3.37	4.44
Losses due to finite conductivity	In the plane metallic surface		0.0063	0.0030	0.0042
	In the waveguide walls		0.0205	0.006	0.0121

DIELECTRIC LOSSES

Electric-type dissipation in the dielectric medium is modelled by the complex relative permittivity

$$\epsilon = \epsilon_{\mathrm{r}} + \mathrm{i}\epsilon_{\mathrm{i}} = \epsilon_{\mathrm{r}}(1 + \mathrm{i}\tan\delta), \tag{4}$$

where ϵ_r is the real relative dielectric constant and $\tan\delta = \epsilon_{\mathrm{i}}/\epsilon_r$ is the loss tangent for the material. The reflected and transmitted power for a lossy structure are plotted in Fig. 5. The structure consists of a lossy hexagonal-puck aperture imbedded in two lossy dielectric layers shown in Fig. 4. The sharp null in the reflection power of the lossless structure does not exist when the losses are added. In Table 1 numerical values of losses in the dielectric medium are presented.

LOSSES IN PLANE METALLIC SCREEN

The metal is supposed to have a finite conductivity, σ_{m}, and to fulfill the condition for a good conductor, *i.e.*, $\sigma_{\mathrm{m}} \gg \omega\epsilon_0\epsilon_{\mathrm{m}}$. The power loss on the plane metallic part of the cell, Ω_{m}, can be written as

$$P_{\text{loss}}^{\text{ml}} = R_{\mathrm{S}} \int_{\Omega_{\mathrm{m}}} |\boldsymbol{H}_{\parallel}|^2 \, \mathrm{d}a, \tag{5}$$

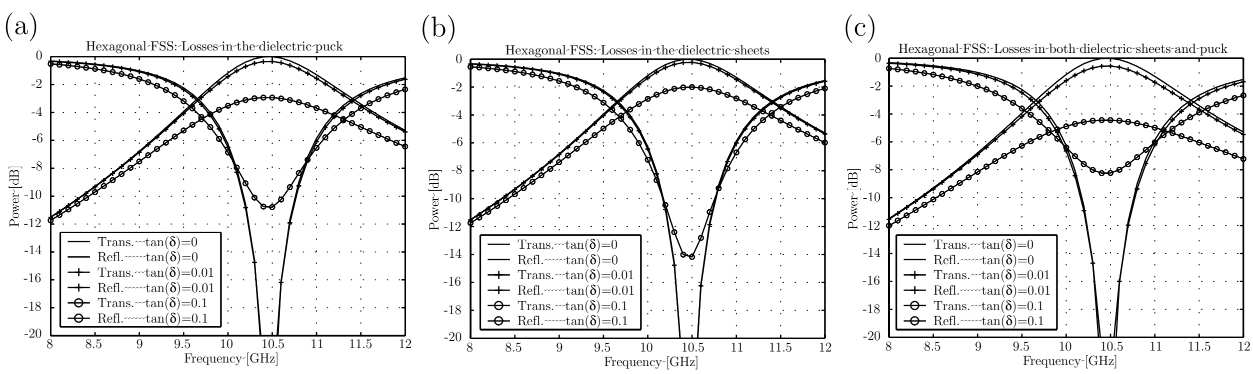

Fig. 5. Dissipation in the hexagonal FSS.

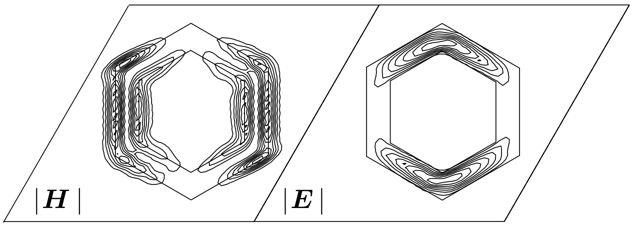

Fig. 6. The electric and the magnetic fields at the metallic surface.

where $R_{\rm S} = 1/(2\sigma_{\rm m}\delta)$ is a surface resistance, δ is the skin depth, and $\boldsymbol{H}_{\|}$ is the tangential component of the magnetic field at the surface of the metallic screen. A very good approximation is that the value of $\boldsymbol{H}_{\|}$ is the same as for a perfectly conducting screen. The loss factor $L_{\rm f}$ due to the finite conductivity in the plane metallic screen is defined as

$$L_{\rm f} = \frac{P_{\text{loss}}}{P_{\text{inc}}}, \tag{6}$$

where P_{inc} incident power on the aperture layer. In Fig. 6 contour plots for the tangential electric and the magnetic fields at the metallic surface for a hexagonal FSS are depicted. The electric field exists only in the aperture and is zero at the metallic surface, whereas the magnetic field exists both in the aperture and at the metallic surface. The loss factor for the metallic surface are presented in Table 1.

LOSSES IN WAVEGUIDE WALLS

Assume that the walls of the waveguide are good, but not perfect, conductors, *i.e.*, the conductivity, σ, is large, but finite. The power loss per unit length can be written as

$$\frac{\mathrm{d}P}{\mathrm{d}z} = -\oint_{\Gamma} \frac{\mathrm{d}P}{\mathrm{d}a}\,\mathrm{d}l = -\frac{1}{2\sigma\delta}\oint_{\Gamma} |\boldsymbol{H}^{\pm}|^2\,\mathrm{d}l, \tag{7}$$

where Γ is the boundary of the aperture. The total magnetic field at the metallic waveguide walls is

$$|\boldsymbol{H}^{\pm}|^2 = \sum_n |\boldsymbol{H}_n^{\pm}|^2 = \sum_n |a_n^{\pm}|^2 \{ |\boldsymbol{H}_{\mathrm{T}n}|^2 + \frac{1}{\eta_0^2}|H_{zn}|^2 \}, \tag{8}$$

where $a_n^{\pm}$ are expansion coefficients. The total power loss in a section of length Δz of the waveguide is given by

$$P_{\text{loss}}^{\text{mw}} = -\frac{\mathrm{d}P}{\mathrm{d}z}\Delta z = P_{\text{inc}} 2\alpha_c \Delta z, \tag{9}$$

where P_{inc} is the incident power through the aperture, and $\alpha_{\rm c}$ is the corresponding attenuation constant of the field due to finite conductivity in the walls of the waveguide. The power losses in the walls of the waveguide are presented in Table 1.

CONCLUSIONS

The losses in the dielectric material are rather small for common ”good dielectrics”, but can be quite large for ”lossy dielectrics”, if the thickness of the layers are large. The attenuation is proportionately larger in the dielectric waveguide puck than in the dielectric layer, and the attenuation becomes smaller if the size of the aperture becomes larger. The losses due to finite conductivity in the metallic plate are small, if the metallic plate is made of a good conductor, such as copper or aluminium. The losses in the waveguide walls are proportionately larger than the losses in the plane metallic surface. The losses on the plane metallic screen and losses on the waveguide walls are smaller, if the aperture are larger. In general, the losses in the dielectric material are dominating over the losses due to finite conductivity in the metallic plate.

REFERENCES

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