

Antenna inside PBG and Fabry-Perot cavities

Halim Boutayeb, Kouroch Mahdjoubi, Anne-Claude Tarot

▶ To cite this version:

Halim Boutayeb, Kouroch Mahdjoubi, Anne-Claude Tarot. Antenna inside PBG and Fabry-Perot cavities. 2002, 4 p. hal-00133824

HAL Id: hal-00133824 https://hal.science/hal-00133824

Submitted on 27 Feb 2007

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers. L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

ANTENNA INSIDE PBG AND FABRY-PEROT CAVITIES

H. BOUTAYEB, K. MAHDJOUBI and A.C. TAROT

Institut d'Electronique et de Télécommunication de Rennes, Université de Rennes 1, Bât. 11 C, Campus de Beaulieu, 35042 Rennes (France). <u>Halim.boutayeb@univ-rennes1.fr</u> Tel : +33 (0) 2 23 23 62 35

Abstract- Photonic crystals are used quite frequently to enhance the antenna gain. To understand the origin of this enhancement we have assimilated the PBG-Antenna structure to a Fabry-Perot cavity, where the source of the incident plane wave is placed inside. The PBG reflecting surfaces are composed of periodic metallic wires. The Fabry-Perot interferometer is usually studied with an excitation source placed outside the cavity. Here we had to extract new formulas for the case of the sources positioned inside the cavity. These simple formulas are found to be very helpful and very precise compared to the exact FDTD simulation. In the second part of the paper a simple model of the antenna is proposed to take into account the interactions between the cavity waves and the antenna.

INTRODUCTION

Placing an antenna inside a PBG structure can allow to obtain an important enhancement of the antenna gain [1-4], but the origin of this improvement is not clearly explained. To better understand the mechanism that creates the gain enhancement, we have revisited the fundamentals of Fabry-Perot cavity by generating the incident wave *inside* the cavity and not outside of it, as it's usually done.

In the first part of this communication we will consider an *ideal* cavity with infinite length in one hand and no interaction (absorption and reflection) between the antenna and the cavity waves in other hand. In the second part, we will propose a simple model for the antenna, used in FDTD method, to take into account some elementary *interactions between the cavity and the antenna*. Research works are going on to improve the source antenna model and to treat the practical case of *finite* length PBG materials.

I- IDEAL STRUCTURE

Let us consider a TM plane wave propagating inside the cavity in both left and right sides (*Figure 1*). The cavity is, in many cases, made of two infinitely long reflecting surfaces composed of PBG materials [1,5,6]. Here, there are composed of single layers of metallic PBG (periodic infinitely long wires) (*Figure 1a*).

The periodic surfaces are characterized by the diameter "**a**" of the wires and the transversal period "**P**_t". *Figure* 2 shows the typical reflection and transmission coefficients (**r**, **t**) of these periodic surfaces with $\mathbf{a}/\mathbf{P}_t = 0.5\%$. **P**_t is maintained smaller than λ to avoid the grating lobes.





By applying the principle of successive reflections and by superimposing the successive output waves (*Figure 1b*), we obtain the transmission coefficient "**T**" (equation (1)) of "Antenna-Cavity" structure. The magnitude of this coefficient represents in fact the "**gain Enhancement G** = $|\mathbf{T}|$ ", because it corresponds to the output wave E_t created by the cavity, relative to the incident wave E_{inc} due to the isolated source/antenna (i.e. without cavity).

$$T = \frac{E_{t}}{E_{inc}} = t_{1} \left(1 + e^{-jk2D_{2}} \left(1 + r_{1}e^{-jk2D_{1}} \right) \sum_{n=1}^{\infty} r_{2}^{n} r_{1}^{n-1} e^{-jk2(n-1)(D_{1}+D_{2})} \right); \qquad \mathbf{G} = |\mathbf{T}|$$
(1)

(r1,t1) and (r2,t2) are the reflection and transmission coefficients of the cavity walls (periodic surfaces) (see top of *Figure 1b*).



Figure 2 : Magnitude of t and r coefficients for a periodic surface of metallic wires of $a/P_t=0.5\%$



Figure 4 : Maximum and minimum envelops ($\mathbf{D}=40mm$, $\mathbf{P}_{t}=40mm$, $\mathbf{a}=2mm$)



Gain G Gain G r,t r,tr,t

Figure 3 : Gain enhancement G. Comparison between FDTD method and formula (2) ($\mathbf{D}=40mm$, $\mathbf{P}_t=40mm$, $\mathbf{a}=2mm$)



Figure 5 : Determination of the transmission pick frequency. (D=40mm, $P_t=40mm$, a=2mm)



Figure 6: (a): Gain and envelop ($\mathbf{D}=41.7mm$, $\mathbf{P}_t=0.9mm$, $\mathbf{a}=0.36mm$) (b): zoom on the transmission pick.

When the two periodic surfaces are identical, the "T" expression is simplified to the relation :

$$T = \frac{t}{1 - re^{-jk2D}}; \qquad G = |T|, \qquad (2)$$

where t1 = t2 = t, r1 = r2 = r and D1 = D2 = D

This formula is valid as far as the distance **D** is larger than P_t [7].

In *Figure 3* the analytical formula (2) is compared to the exact gain value obtained by a FDTD simulation. One can see that there is a perfect agreement between the results.

It is interesting to note that the maximum and minimum of G are given respectively by the envelop curves $\frac{|l|}{1-|r|}$

and $\frac{|\mathbf{t}|}{1+|\mathbf{r}|}$, as it is shown in *Figure 4*. Note that the *gain* value can *theoretically become very large*. *Figure 6*

illustrates the results obtained for a second example of periodic surface (D=41.7mm, $P_t=0.9mm$, a=0.36mm) for which the maximum gain can reach 80. In practice, this maximum can be unreachable because of the interactions between cavity waves and the non ideal source (antenna). In section II of this communication a rudimentary source model is proposed to obtain a better approximation for the gain enhancement.

We would like to mention at this point that this gain improvement is not associated to any "*directivity improvement*", because actually the incident and transmitted waves E_{inc} and E_t are both plane waves, having already the maximum directivity.

Furthermore, the pick frequency can be obtained by applying resonance condition $\varphi_r = 2kD-2n\pi$, where $k=2\pi f/c$; n=0, 1, 2, ...and φ_r is the phase of "**r**" (cf. *Figure 5*).

II- A SIMPLE MODEL OF THE ANTENNA

A real antenna interacts with cavity waves by diffracting and absorbing them partly. As the waves are plane the diffraction leads to reflection and transmission waves. Then we consider the reflection coefficient \mathbf{r}_a and the transmission coefficient \mathbf{t}_a due to the antenna itself (see *Figure 7a*). Note that the antenna absorption leads to the condition $|\mathbf{r}_a|^2 + |\mathbf{t}_a|^2 < 1$. Using these parameters allows to obtain the new transmission coefficient taking into account the antenna presence :

$$T_{2} = \frac{t}{1 - r(r_{a} + t_{a})e^{-jk2D}}; \qquad G_{2} = |T_{2}|$$
(3)



Figure 7 : (a) : Antenna interacting with cavity waves (b) : Antenna model composed of an infinite plane of point voltage sources in series with point resistances (\mathbf{R})

In FDTD method, the incident wave is created by an uniform distribution of *ideal* voltage sources placed all over the antenna plane and having no interaction with the cavity waves. To modelize the effect of the antenna we have added a resistance " \mathbf{R} " in series with each ideal source (*Figure 7b*).

Figure 8 shows new gain results G_2 for the example of $R=2 k\Omega$. We observe a very good agreement between the FDTD solution and the formula (3). We can also note the new maximum an minimum envelops in *Figure 8b*.

The magnitude of reflection (\mathbf{r}_a) and transmission (\mathbf{t}_a) coefficients of the new source (antenna) are given in *Figure 9a*. The phases of \mathbf{r}_a and \mathbf{t}_a (not shown here) are relatively constant and equals to π and 0, respectively.

Figure 9b gives G_2 as a function of **R**. There are two extremum cases: small $|\mathbf{r}_a|$ and large $|\mathbf{r}_a|$. For small $|\mathbf{r}_a| \approx 1$, $(|\mathbf{t}_a| \approx 1)$, G_2 has the same form as the ideal case (*Figure 3& Figure 9b*); When $|\mathbf{r}_a| \approx 1$ ($|\mathbf{t}_a| \approx 0$) the pick frequency is approximately twice that of the ideal case (*Figure 9b*, $\mathbf{R}=1\Omega$). In this case, the antenna itself becomes a perfect reflecting plane ($\mathbf{r}_a \approx -1$), giving rise to a new cavity composed of only one periodic surface. For these extremum cases the gain maximum is limited by the same envelop as in *Figure 4*. The case of real antennae is somewhere in between the two extreme cases. One notes that the gain due to the real antenna is less than that of extremum cases.



Figure 8: Gain enhancement G_2 for D=40mm, $P_t=40mm$, a=2mm, $R=2k\Omega$ (a) : comparison between FDTD method and formula (3) (b) : maximum and minimum envelops



Figure 9 : (a) : Magnitude of reflection (\mathbf{r}_{a}) and transmission (\mathbf{t}_{a}) coefficients of the plane antenna for various values of \mathbf{R} (b) : Gain \mathbf{G}_{2} for various values of series resistance \mathbf{R} (\mathbf{D} =40mm, \mathbf{P}_{t} =40mm, \mathbf{a} =2mm)

CONCLUSION

Inserting an antenna inside a cavity allows to enhance largely its gain. However the gain improvement does not mean directivity improvement. Indeed, the wave front, with and without cavity, remains the same (i.e. plane wave). Hence, the directivity, with and without cavity, does not change.

We have first studied the gain improvement due to a Fabry-Perot cavity effect. Then we have proposed a more realistic source and compared the ideal and non ideal results. We continue to work on models for real sources and we consider treating real cavities where the physical dimensions are finite. We are also studying conformal cavities to replace the Fabry-Perot one.

REFERENCES

[1] B. Telmulkuran, E. Ozbay, J. P Kavanaugh, G. Tuttle, and K.M. Ho, "Resonant cavity enhanced detectors embedded in photonic crystal", Applied Physics letters, volume 72 number 19, 11 May 1998.

[2] R. Biswas, E. Ozbay, B. Temelkuran, Mehmet Baydindir, M. M. Sigalas and K.-M. Ho, "Exceptionally directional sources with Photonic Band-Gap crystals", Optical Society of America, volume 18, number 11, November 2001.

[3] S. Enoch, Nicolas Guérin, Gérard Tayeb, Patrick Vincent, "Study of photonic crystal based directive antennas", ESTEC 2001.

[4] M. Thevenot, C. Cheypre, A. Reineix and B. Jecko, "Directive Photonic Band-Gap Antennas", IEEE Trans. On Microwave Theory and Technics, vol. 47, no. 11, November 1999.

[5] D.R. Smith, S. Schultz, N. Kroll, M. Sigalas, K.M. Ho and C.M. Soukoulis, "Experimental and theoretical results for a twodimensional metal Photonic Band-Gap cavity". Applied Physics letters, volume 65 number 5, 1 August 1994.

[6] E. Ozbay, B. Telmulkuran, M. Sigalas, G. Tuttle, M. Soukoulis and K.M. Ho, "Defect structures in metallic photonic crystals", Applied Physics letters, volume 69 number 25, 16 December 1996.

[7] H. Boutayeb, K. Mahdjoubi, A.C Tarot and S. Collardey, "Problème de caractérisation des matériaux à Bande Interdite Photonique de taille finie", JCMM, Toulouse, Mars 2001.