ANTENNA INSIDE PBG AND FABRY-PEROT CAVITIES

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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

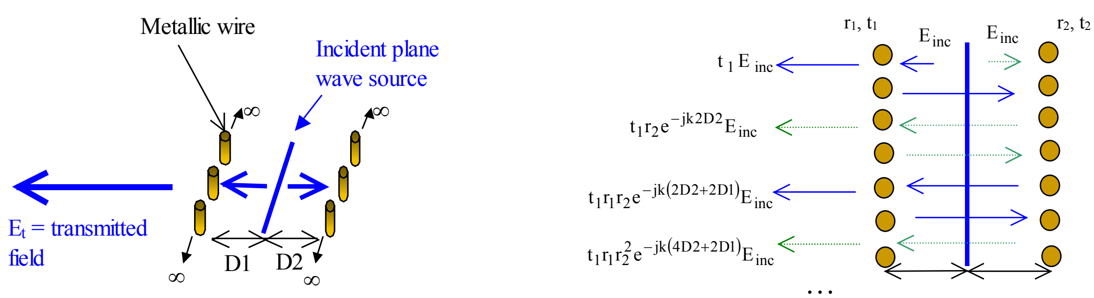
Placing an antenna inside a PBG structure can allow to obtain an important enhancement of the antenna gain *[1-4],* but the origin of this improvement is not clearly explained. To better understand the mechanism that creates the gain enhancement, we have revisited the fundamentals of Fabry-Perot cavity 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 "$\mathbf{P_t}$". *Figure 2* shows the typical reflection and transmission coefficients (**r, t**) of these periodic surfaces with $\mathbf{a/P_t}$ = 0.5%. $\mathbf{P_t}$ is maintained smaller than λ to avoid the grating lobes.



(a) (b)

Figure 1 : Antenna inside a Fabry-Perot cavity. (a) : geometry (b): calculation of the transmitted wave

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 = |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).

$$T = \frac{E_t}{E_{inc}} = t_1\left(1 + e^{-jk2D_2}\left(1 + r_1 e^{-jk2D_1}\right)\sum_{n=1}^{\infty} r_2{}^n r_1{}^{n-1} e^{-jk2(n-1)(D_1+D_2)}\right) \;; \qquad \mathbf{G= |T|} \qquad (1)$$

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

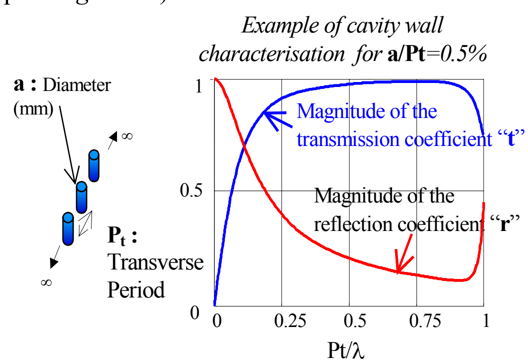


Figure 2 : Magnitude of **t** *and* **r** *coefficients for a periodic surface of metallic wires of* **a**/$\mathbf{P_t}$*=0.5%*

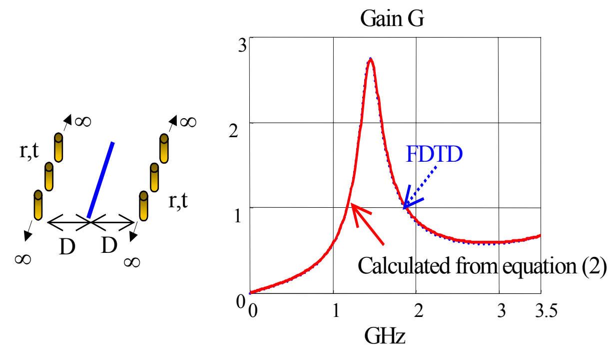


Figure 3 : Gain enhancement G. Comparison between FDTD method and formula (2) (**D***=40mm,* $\mathbf{P_t}$*=40mm,* **a***=2mm)*

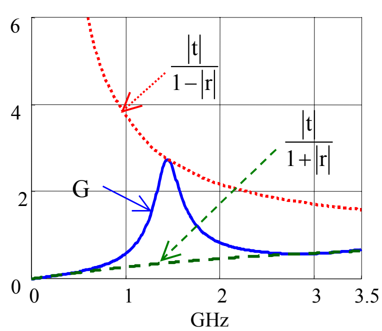


Figure 4 : Maximum and minimum envelops (**D***=40mm,* $\mathbf{P_t}$ *=40mm,* **a***=2mm)*

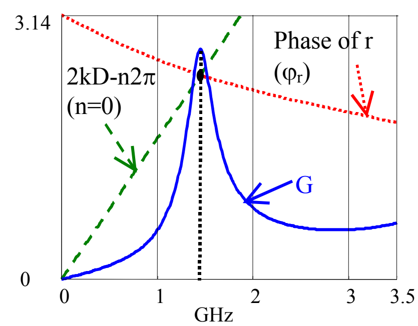


Figure 5 : Determination of the transmission pick frequency. (**D***=40mm,* $\mathbf{P_t}$ *=40mm,* **a***=2mm)*

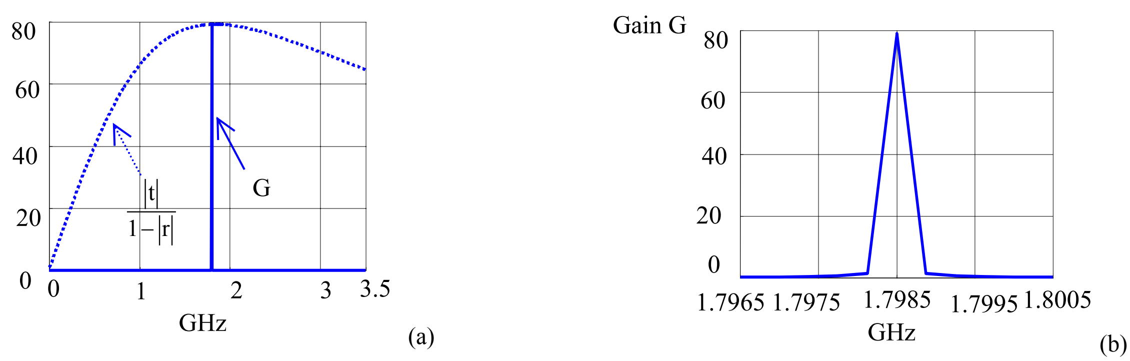


*Figure 6 : (a) : Gain and envelop (***D***=41.7mm ,* $\mathbf{P_t}$ *=0.9mm,* **a***=0.36mm) (b) : zoom on the transmission pick.*

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

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

where **t1** = **t2**= **t** , **r1** = **r2** = **r** and **D1 = D2 = D**
This formula is valid as far as the distance **D** is larger than $\mathbf{P_t}$ *[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 $\frac{|t|}{1-|r|}$ and $\frac{|t|}{1+|r|}$, 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,* $\mathbf{P_t}$=*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 φ_r = 2kD-2nπ, where k=2πf/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 :

$$T_2 = \frac{t}{1-r(r_a+t_a)e^{-jk2D}}\,; \qquad \mathbf{G_2}=|\mathbf{T_2}| \tag{3}$$

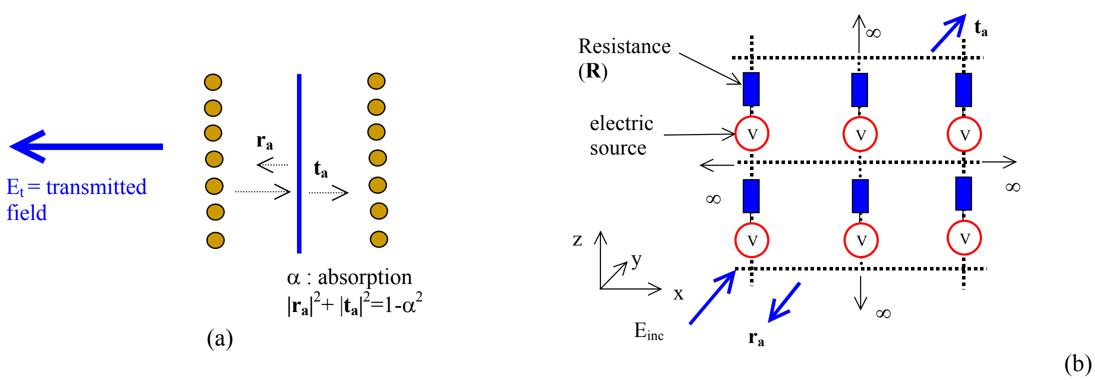


*Figure 7 : (a) : Antenna interacting with cavity waves (b) : Antenna model composed of an infinite plane of point voltage sources in series with point resistances (***R***)*

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 "**R"** in series with each ideal source (*Figure 7b*).

Figure 8 shows new gain results $\mathbf{G_2}$ for the example of **R**=2 kΩ. 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 $\mathbf{G_2}$ as a function of **R**. There are two extremum cases: small $|\mathbf{r_a}|$ and large $|\mathbf{r_a}|$. For small $|\mathbf{r_a}|$ ($|\mathbf{t_a}| \cong 1$), $\mathbf{G_2}$ has the same form as the ideal case (*Figure 3& Figure 9b*); When $|\mathbf{r_a}| \cong 1$ ($|\mathbf{t_a}| \cong 0$) the pick frequency is approximately twice that of the ideal case (*Figure 9b*, **R**=1Ω). In this case, the antenna itself becomes a perfect reflecting plane ($\mathbf{r_a} \cong -1$), 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.

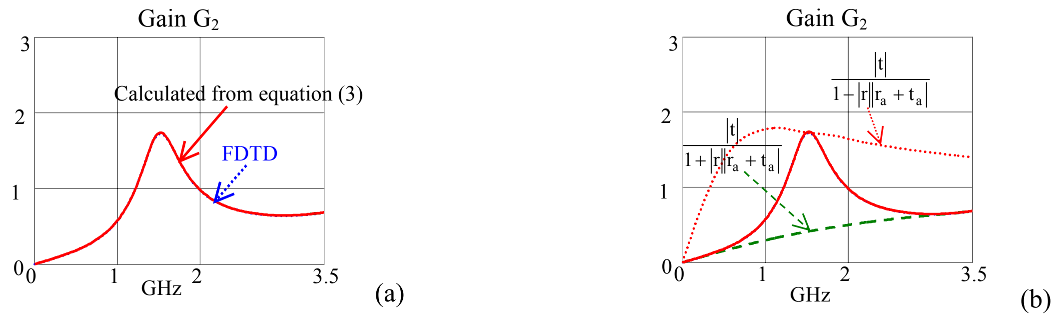


Figure 8 : *Gain enhancement* $\mathbf{G_2}$ *for* **D**=*40mm,* $\mathbf{P_t}$=*40mm,* **a**=*2mm,* **R**=*2k*Ω *(a) : comparison between FDTD method and formula (3) (b) : maximum and minimum envelops*

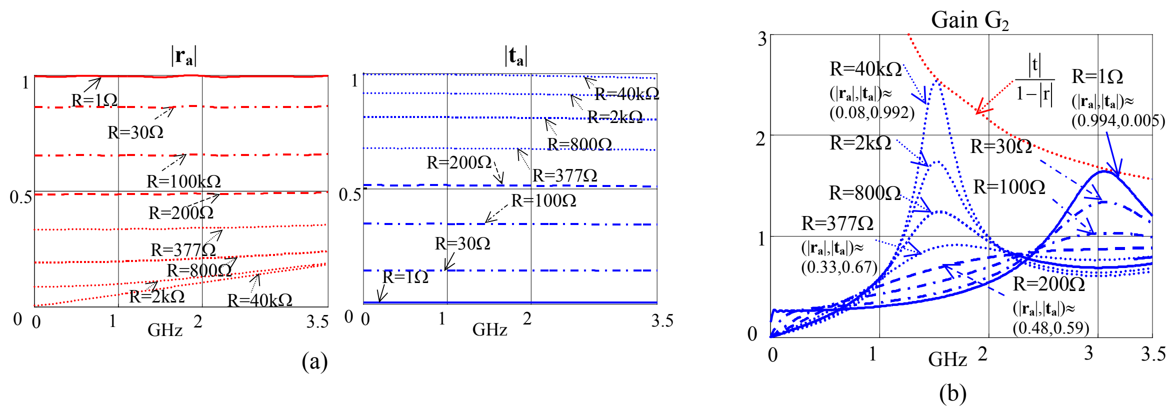


Figure 9 : (a) : Magnitude of reflection ($\mathbf{r_a}$*) and transmission (*$\mathbf{t_a}$*) coefficients of the plane antenna for various values of* **R** *(b) : Gain* $\mathbf{G_2}$ *for various values of series resistance* **R** *(***D**=*40mm,* $\mathbf{P_t}$=*40mm,* **a**=*2mm)*

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.

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