# Study on the Electromagnetic Coupling of Slots with Finite Thickness in the Parallel-Plate Structure

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In this paper, the electromagnetic coupling problems are tackled on slots with nonzero thickness. The analysis is carried out by combination of the thin-wire concept and the Method of Moment(MoM) for the sake of improving computation efficiency. Under the conditions to be presented, slots can be replaced with wires that have effective radii. Also, the infinite summation-type Green's functions are calculated for the parallel-pale structure. A slot in an infinite ground is analyzed and its results are compared with the measurement in a literature. Furthermore, it is examined how the slots couple in parallel plates.

## I. INTRODUCTION

As frequency becomes higher, electromagnetic energy couples in more complex manners through objects such as slots, etc. If it undesirably influences the operation of a system, in order to suppress the disturbance, the electromagnetic interference or coupling should be robustly predicted before its design and fabrication stage.

It has been an interesting topic that the spurious electromagnetic energy of high frequency can penetrate, through slots, from the external region to the internal one of an aircraft or something. This type of problem has been characterized in a wide range of ways. One is using parallel plates with slots or apertures[1-4].

The Method of Moment is used as a framework to analyze the electromagnetic phenomena occurring at the aperture on parallel plates. In applying this method to the parallel plate case, a summation-type Green's functions should be included in solving mixed potential integral equations(MPIE's). The multiple integrals including the non-closed-form Green's functions can be calculated efficiently, combined with the thin-wire concept of a recent literature as long as specific conditions are met[5].

First, a slot in an infinite ground is analyzed for the validity of the present method. Next, the coupling of slots with thickness are investigated for the parallel-plate structure.

## II. Theory

At a high frequency regime, the electromagnetic coupling into the parallel plates through a thick slot can be depicted as shown in Figure 1. The electromagnetic field is incident from the external region and is coupled to the inside of the parallel plates through the slot. If the thickness and width of the plate are less than its length and the wavelength, it can be equivalent to a magnetic-current wire with the following effective radius[4].

$$a_{eff} = (w_s/4)\exp[-\pi d_s/(4w_s)] \qquad (1)$$

where $w_s$, $l_s$ and $d_s$ are the width, length and depth, respectively, of the slot and $w_s$, $d_s << \lambda$, $l_s$.

To solve this problem, the boundary condition for the tangential magnetic fields on the aperture is applied as follows.

$$\overline{H}^{s,-} + \overline{H}^{i,-} + \overline{H}^{r,-} = \overline{H}^{s,+} \qquad (2)$$

Superscripts + and - refer to $z = 0^+$ and $0^-$, and $i$, $r$ and $s$ stand for the incident, reflected and scattered fields, respectively. The incident magnetic field is

$$\bar{H}^{i,-} = \hat{k}^i \times \hat{\alpha} \frac{e^{-j\bar{k}^i \cdot r^i}}{\eta} \qquad (3)$$

where

$k = \sqrt{\varepsilon_0 \mu_0}$ , $\eta = \sqrt{\frac{\mu_0}{\varepsilon_0}}$ , $\bar{k}^i = k_x^i \hat{x} + k_y^i \hat{y} + k_z^i \hat{z}$ ,

$\hat{k}^i = \frac{\bar{k}^i}{k}$ and $\bar{r} = x\hat{x} + y\hat{y} + z\hat{z}$ . $\varepsilon_0$ and $\mu_0$ are permittivity and permeabilty, respectively. $\bar{k}^i$ is the propagation vector of incidence. $\hat{\alpha}$ is the polarization vector of the incident electric field, and time dependence $e^{j\omega t}$ is assumed throughout the work. The scattered magnetic fields inside and outside the parallel plate can be written as

$$\bar{H}^{s,\pm} = -j\frac{k_\pm}{\eta_\pm} \bar{F}^\pm(\bar{r}) - \nabla\phi_m^{\pm}(\bar{r}) \qquad (4)$$

where $k_+ = \sqrt{\varepsilon_r} k$ , $k_- = k$ , $\eta_+ = \frac{\eta}{\sqrt{\varepsilon_r}}$ , $\eta_- = \eta$ , and $\varepsilon_r$ is the relative permittivity.

$\bar{F}^\pm(\bar{r}) = \int \bar{\bar{g}}^\pm{}_{m'n'}(\bar{r},\bar{r}') \cdot M_s^{\pm}(\bar{r}')d\bar{r}'$ , $\bar{\bar{g}}^\pm{}_{m'n'}(\bar{r},\bar{r}')$ is the dyadic Green's function, $M_s^\pm$ is the magnetic current density, and $m'$ and $n'$ stand for the directions of the vector potential and magnetic point source. $\phi_m^\pm(\bar{r})$ is the scalar potential, which is $\phi_m^\pm(\bar{r}) = j\frac{C}{k_\pm}\nabla \cdot \bar{F}^\pm(\bar{r})$. $\nabla$ is gradient and $C$ is the light velocity. $\bar{\bar{g}}^-{}_{m'n'}(\bar{r},\bar{r}')$ is a free space dyadic Green's function and $\bar{\bar{g}}^+{}_{m'n'}(\bar{r},\bar{r}')$ is represented as

$$\bar{\bar{g}}^+{}_{m'n'}(\bar{r},\bar{r}') = \hat{m}'\hat{n}' \sum_{n=-\infty}^{+\infty} \frac{e^{-jk_+\sqrt{(x-x')^2+(y-y')^2+(z-z'+2nw)^2}}}{4\pi\sqrt{(x-x')^2+(y-y')^2+(z-z'+2nw)^2}} \qquad (5)$$

where $w$ is the separation of the two parallel plates. The Green's functions entail the multiple integrals as performing the basis expansion and testing procedure of the conventional MoM application. Subsequently, the related matrix equations are routinely solved for the MPIE solution.

## III. Numerical results

$(\varepsilon_r\varepsilon_0, \mu_0)$ and $(\varepsilon_0, \mu_0)$ are the materials which fill regions $(+)(z>0)$ and $(-)(z<0)$, respectively, In Figure 1. From a practical point of view, it is assumed that $\varepsilon_r = 1$ and the x-polarized magnetic field is normally incident on the slot

First, infinite-summation-type Green's function $\bar{\bar{g}}^+{}_{m'n'}(\bar{r},\bar{r}')$ is calculated, and compared with free space Green's function $\bar{\bar{g}}^-{}_{m'n'}(\bar{r},\bar{r}')$. For computation, the frequency is 1GHz. In addition, 50 is found to be proper for the convergence of the summation. As the distance increases from the singular point to the observation one the electromagnetic fields captured between the plates vary non-monotonically due to image sources as shown in Figure 2.

Second, the computed slot-coupling is compared to the measurement in [5]. The slot has 0.01" as width, 0.125" as depth and 2" as length, which is in an infinite ground. Therefore, the effective radius of the corresponding wire amounts to $1.8858 * 10^{-13}$ m. The observation point is (0.m, 0.1334m, 0.001m). In Figure 3, one extreme point occurs along the plotted curve of the coupling in region $(+)$. This is almost the same value as discovered in the measurement.

Third, based upon the present analysis method, the parallel-plate structure is investigated. The slot for this case is what has been used for the infinite ground case.

0.2m is given as the gap between the two plates. Figure 4 shows the analysis results of both the infinite ground and parallel plate cases. Between the parallel plates, the coupling of the infinite-ground case is perturbed by the multiple scattering mechanism. However, the two cases have maximum points at around one frequency point. This means if the slot with finite thickness does not change the resonance-like characteristic can be maintained .

## IV. Conclusion

Slots with finite thickness have been considered on the electromagnetic coupling. The thin-wire concept has been incorporated to the MoM to more efficiently characterize the coupling problems. Through the work, the resonance–like properties mainly rely on the physical dimensions of slots. This will provide useful information on the slot coupling or interference in other related cases.

## References

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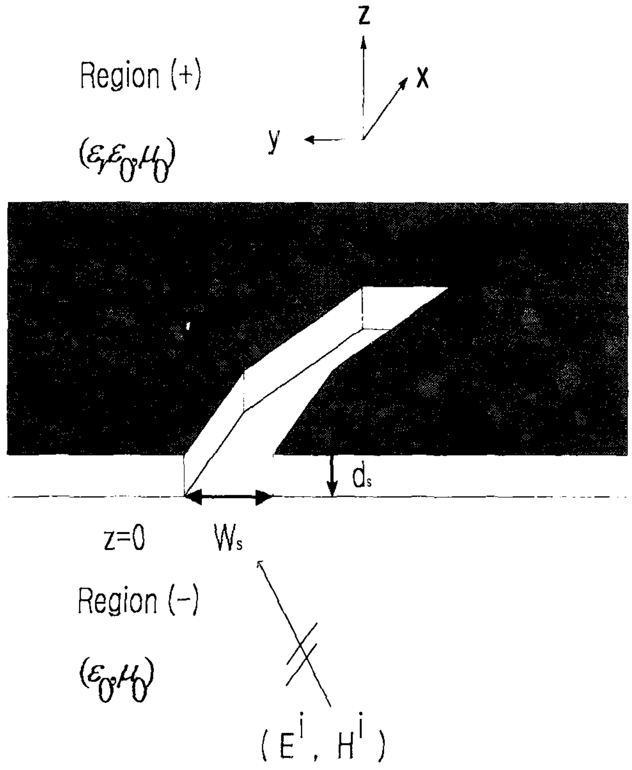


Figure 1. Field impinging through a slot with nonzero thickness

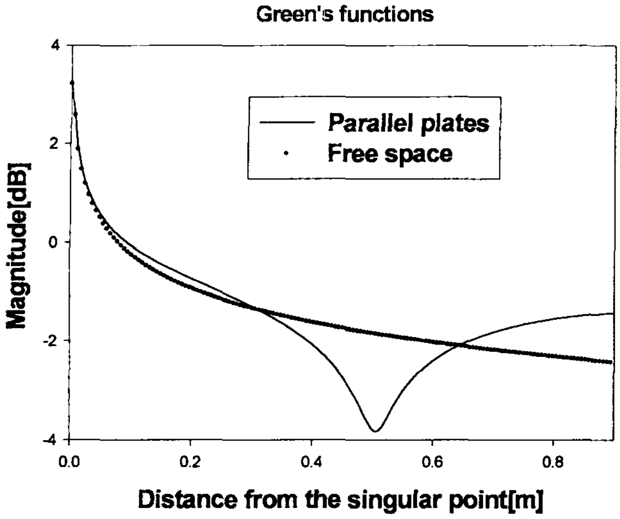


Figure 2 Green's functions for Parallel plates and Free-space

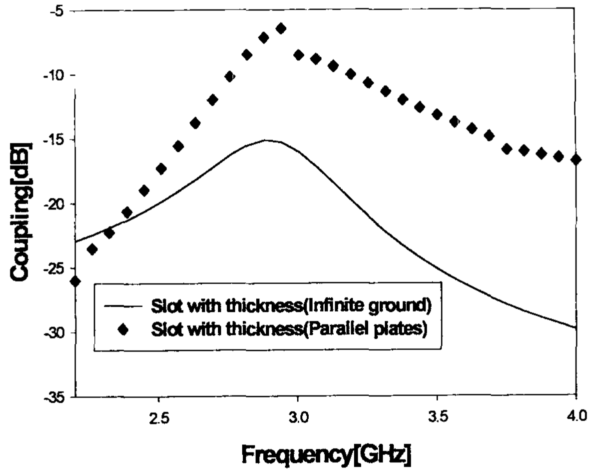


Figure 4 Coupling through a slot in an infinite ground and a parallel-plate structure

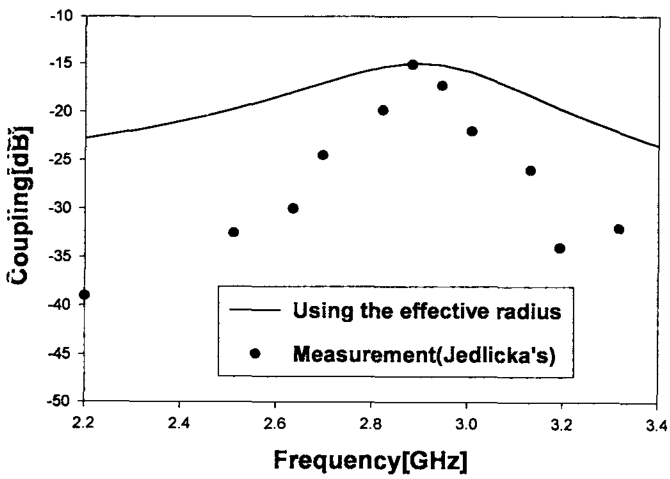


Figure 3 Computation and Measurement for coupling through a slot in an infinite ground