# Accurate Modeling of Metal Plate-Loaded Loop-Coupled Cavities with Slots

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***Abstract*—In this letter, we analyze the problem of the electromagnetic field radiated from apertures in coaxial fed metal enclosures loaded with metal inserts. Such situations are found, for example, in PC environments where slots and apertures are used for the purpose of heat dissipation, CD-ROMs, cable penetration etc. We derive an accurate model of the entire structure, including the coaxial line-to-loop-to-cavity feed and the inner metal planes, simulating the presence of the circuitry inside. The analysis is developed by means of the hybrid transmission line matrix-integral equation (TLM-IE) method and theoretical results are compared with experimental ones showing very good agreement. The evaluation of the reflection coefficient and of the level of radiated emission as functions of the metal plates position is very helpful toward the engineering design of the entire structure. The numerical simulations require rather low computational effort.**

***Index Terms*—Apertures, integral equation, metal enclosures, radiated emission, TLM.**

## I. Introduction

METAL cavities with apertures are widely used in many electromagnetic applications such as the shielding of electronic equipment. The presence of high-frequency fields in the cavity generates spurious radiation through the slot, which is source of interference with other equipment, [1]. Typically, the feed to the circuitry internal to the cavity is provided by a coaxial line, whose inner conductor is short-circuited by means of a loop down to ground. Inside the box, metal plates may be placed: they represent the ground of large mother boards supporting several PCBs. This is a realistic situation representing a clock-circuit inside a PC terminal. Several techniques have been applied to the modeling of the empty slotted cavity, as in [1]. The difficulty arises in modeling the complete structure, comprising the feeding mechanism and the metal plates inside. The goals of the present contribution are the following:

1) modeling the empty structure, including the coax feed and evaluating of the scattering parameters;
2) modeling the cavity loaded by ground planes.

The e.m. analysis is performed by means of the TLM-IE method. The latter is a hybrid approach in the time-domain combining the advantages of the TLM method [2], that is very flexible in modeling arbitrarily shaped complex structures and the advantages of the IE method, that is very efficient in modeling the free space region, [3]. The TLM-IE method is, in fact, efficient and versatile in modeling transient radiation phenomena in microwave structures, [4], [5]. For the case of the empty cavity, the theoretical results are compared with experimental ones reported in the literature [1], showing very good agreement. For the case of the loaded cavity we investigate the shift of the resonant frequencies and the level of the radiated emission as function of the position of the metal plates. The numerical simulations, performed on a PC, require very low computational effort.

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## II. Theory

The theory of the TLM-IE method is reported in [4], [5]; in this approach the three-dimensional space is segmented into different subregions, where the best suited method, be it TLM or IE is applied. At the boundary surfaces of the discretized subregions the e.m. tangential field components are sampled and represented by means of subdomain basis functions. By applying the field continuity and using the Method of Moments (MoM) technique we derive a matrix system for the tangential field components, [4], [5]. In the present case, the e.m. field inside the cavity is modeled by the TLM method, that is able to discretize the complex shape of the coax-feed as well as the insertion of metal plates, (see Fig. 1). Outside the cavity, in the free-space region, the e.m. field is represented by means of the free-space Green's function. The boundary between the two regions is represented by the surface of the rectangular aperture, where the TLM and IE methods are matched. By using the analytical Green's function in free-space, we avoid the disadvantages of the TLM method, which occur in modeling the e.m. field in open space regions, where the number of the cells increases very rapidly together with the computational time and memory requirement.

## III. Results

We analyze the metallic cavity shown in Fig. 1; its dimensions are: $a = 100$ mm, $b = 337$ mm, $c = 160$ mm, with an aperture of dimensions 228 × 10 mm. The cavity is fed by a metal loop formed by the twisted inner conductor of a coaxial cable placed at $y = 62$ mm, $z = 60$ mm. The coaxial line is connected to a voltage generator, as shown in Fig. 1 and we consider a feed current of 1 A. Inside the cavity we apply the TLM algorithm with Symmetrical Condensed Node (SCN) and homogeneous mesh ($\Delta x = \Delta y = \Delta z = 2$ mm). The circular transverse section of the coaxial line-loop-cavity is modeled by TLM as a sequence of "square" sectors. The excitation pulse is a sinusoidal electric field modulated by a wideband Gaussian distribution (100 MHz–3 GHz). The analysis is performed in the time-domain and FFT translates the results to the frequency domain.

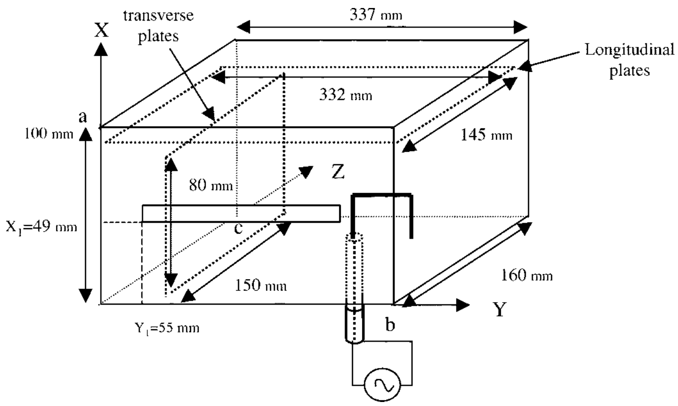


Fig. 1. Analyzed cavity. Dimensions: $a = 100$ mm, $b = 337$ mm, $c = 160$ mm. Aperture coordinates: $X_1 = 49$ mm, $Y_1 = 55$ mm. Position of the feeding loop: $y = 62$ mm, $z = 60$ mm. Dimensions of the metal plates. Longitudinal: 332 × 145; transverse: 80 × 150.

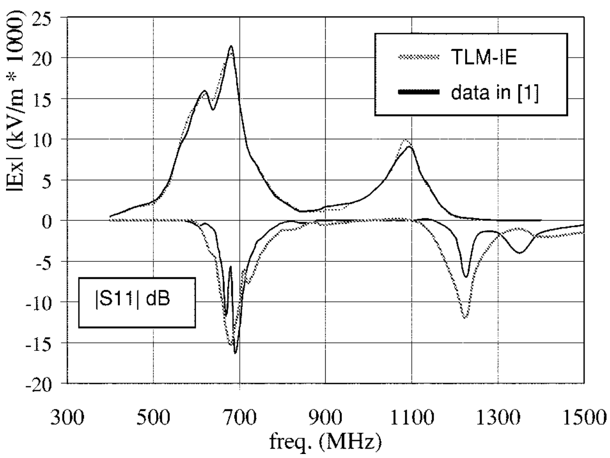


Fig. 2. Empty cavity. Upper side: theoretical $E_x$-field amplitude (in KV/m) at the center of the aperture compared with the data reported in [1]. Lower side: reflection coefficient amplitude compared with experimental results, [1].

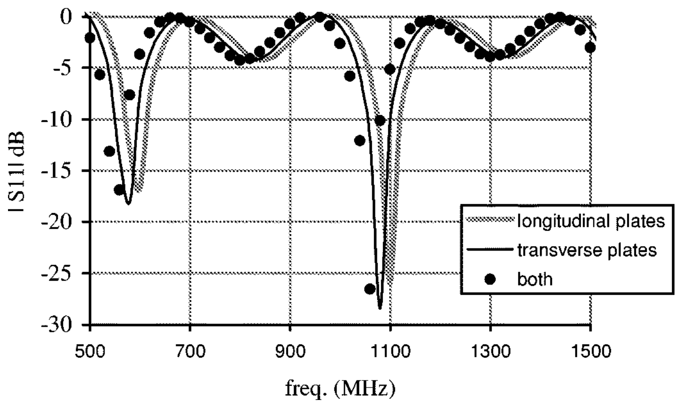


Fig. 3. Loaded cavity. Reflection coefficient amplitude, evaluated by the TLM-IE method, in the cases (a)–(c) of Fig. 1.

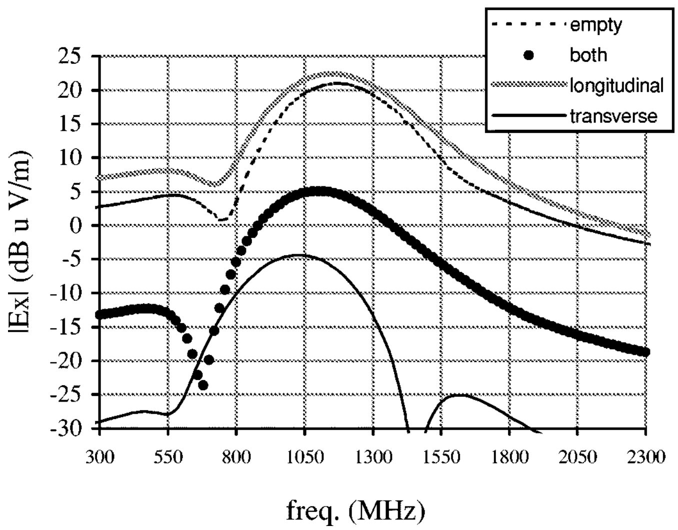


Fig. 4. Loaded cavity: $E_x$-field amplitude (dB $\mu$V/m) at a distance of $R = 4$ m from the aperture, normalized to the $E_x$-field on the aperture and compared with the case of empty cavity.

*Empty Cavity:* In Fig. 2 (upper side), we show the theoretical $E_x$-field amplitude (the main field component in this configuration), evaluated at the center of the aperture and compared with the data reported in [1]. We note three main resonances at, about, $f = 640$, $f = 660$, $f = 1100$ MHz due to the presence of the loop, of the aperture and of the cavity, respectively. In Fig. 2 (lower side), we report the calculated reflection coefficient compared with the measured one [1].

*Loaded Cavity:* Now we insert metal plates inside the cavity. In case (a) we insert three plates, placed normally with respect to the $y$-axis (at $y = 115, 165, 215$ mm), indicated as "transverse plates" in Fig. 1. In case (b), we consider a single plate in the plane $y$–$z$, at $x = 85$ mm, ("longitudinal plate"). In case (c), we consider both the transverse and the longitudinal loading plates.

Fig. 3 shows the calculated reflection coefficient in case (a), (b), and (c). The insertion of reactive elements causes a different distribution of the electric and magnetic energy and a shift of the resonances.

In Fig. 4, we report the radiated $E_x$-field (at a distance of 4 m) compared to the case of empty cavity. In case (a) we have a lower level of radiated field: this is due to the metal plates in the plane $x$–$z$, which cause a null $x$-tangential field on the plates and a decreasing $E_x$-field on the aperture. Dually, by inserting a longitudinal plate, the normal $E_x$-field becomes stronger: this produces an increase of the $E$-field on the aperture, which, in turn, increases the emitted radiation. In case (c), we have the combination of the two effects. The computational time is about 30 CPU-min using a 500-MHz PC, 500 MByte-RAM.

## IV. Conclusions

In this contribution we present an accurate analysis of the radiation from a cavity with apertures fed by coaxial cable and loaded with metal plates. The proposed model simulates a realistic PC terminal with its clock circuitry. The e.m. analysis is performed by the TLM-IE method, that is very efficient for problems in which structures of complex shape are interfaced to free-space. For the case of the empty cavity theoretical results are compared with experimental ones, showing good agreement. For the case of the loaded cavity the variation of the reflection coefficient as function of the position of the metal plates permit us to investigate the shift of the resonant frequencies. The level of the emitted radiation appears to be very sensitive to the geometry and the location of the loading plates.

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