Analysis and Compensation of the Effect of the Enclosure in a Multichannel RF Front-End

Ramón López La Valle, *Member, IEEE,* Javier G. García, and Pedro A. Roncagliolo

***Abstract*—The aim of this work is to analyze the resonant frequencies of the enclosure of a multichannel RF front-end intended for receiving the GPS signals. The obtained results show that the resonant modes of the designed enclosure can degrade the performance of the receiver. In order to overcome this problem, we propose to use an absorber material for damping the cavity resonances. Measurements carried out demonstrate the effectiveness of the implemented solution.**

***Index Terms*—Cavity resonance, electromagnetic shielding, interference suppression, mutual coupling.**

I. INTRODUCTION

FOR electromagnetic compatibility reasons, many electronic devices that operate at microwave frequencies are placed inside metallic cavities to provide shielding. However, a metallic enclosure or cavity can resonate at microwave frequencies [1]. Particularly, if the resonance frequencies of the cavity are within the frequency operating range of the enclosed electronic device, a performance degradation is possible [2]-[3].

In this work we analyze the resonances of the enclosure of a four channel RF front-end designed for receiving the signals of the Global Positioning System (GPS). This front-end is capable of operating in two frequency bands known as L1 and L2, which center frequencies are 1575.42 MHz and 1227.6 MHz respectively [4]. Dual-band front-ends are used in high precision GPS receivers since two different frequencies are needed to calculate the ionospheric delay, that is one of the main error sources in the position estimation of conventional single-frequency receivers [5].

Because of this front-end is part of a four antenna GPS receiver that selects the best input antenna for each visible satellite, the coupling between the different channels (antennas) needs to be low [6]. In fact, this application requires at least 40 dB of isolation between the channels. Considering the frequency range of operation of the front-end, the resonance frequencies of the enclosure should be calculated in order to evaluate their effect on the receiver's performance.

The simulations carried out show that some resonance frequencies of the proposed enclosure are near the center frequencies of the L1 and L2 bands. These resonant modes can affect the front-end, specially increasing the coupling between the channels or generating spurious oscillations.

There have been different methods to fix the cavity resonant problems [3] [7]. Some of these methods require changes in the design of the enclosure. For instance, the size of the enclosure can be reduced to increase the frequency of the resonant modes in order to avoid affecting the device enclosed. Another possible solution consists of disrupting the standing wave associated to a specific risky resonant mode by locating some posts inside the enclosure. In the present case of study, the aforementioned solutions are not applicable because the enclosure design cannot be modified. Therefore, the use of an absorber material seems to be an adequate alternative [8]. Particularly, we have proposed to place the absorber material on the cover of the enclosure. The obtained results were very satisfactory since the resonance modes were effectively damped.

The rest of the work is organized as follows. The Section II introduces the problem of the resonances in a cavity. The Section III presents the simulation results of the enclosure studied in this work. In Section IV we describe the proposed solution and present the new simulations. The Section V shows the measurement results that confirm the effectiveness of the implemented solution. Finally, the conclusions are given in Section VI.

II. ENCLOSURE RESONANCE

The resonance frequencies of a rectangular enclosure filled with a homogeneous material can be easily calculated by [1]

$$f_{mnl} = \frac{1}{2\sqrt{\varepsilon\mu}}\sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{l}{c}\right)^2} \tag{1}$$

where a, b, and c are the dimensions of the cavity, ε and μ are permittivity and permeability of the filling material, and m, n and l are integers.

The enclosure analyzed in this work, whose 3D model is shown in Fig. 1, is not completely rectangular and it is composed of two cavities. There is one cavity above the printed circuit board (PCB) and another underneath, which acts as a shield between the top and the bottom layers of the PCB. For this geometry, (1) may provide an approximate solution. However, to achieve accurate results, the resonance frequencies should be determined by solving the Maxwell's equations with the corresponding boundary conditions for the region defined by the enclosure.

Particularly, using the Faraday's and Ampere's laws, assuming time harmonic fields, and considering the general case of a cavity filled with a lossy dielectric material, we can obtain the following expression

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Authors are with UIDET SENyT, Departamento de Electrotecnia, Facultad de Ingeniería, Universidad Nacional de La Plata, La Plata 1900, Argentina e-mail: lopezlavalle@ing.unlp.edu.ar.

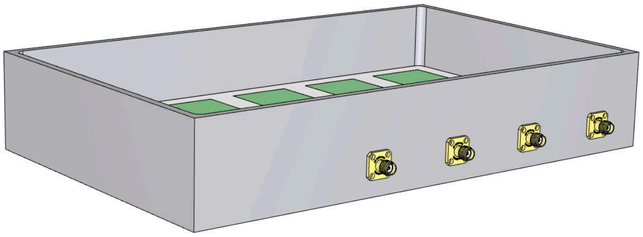


Fig. 1: 3D model of the enclosure.

$$\nabla \times (\nabla \times \mathbf{E}) = \omega^2 \mu \left(\varepsilon - j\frac{\sigma_d}{\omega}\right)\mathbf{E} \tag{2}$$

where σ_d, ε, and μ are the conductivity, dielectric permittivity, and magnetic permeability of the filling material respectively. The values of ω that satisfy (2) are the eigenvalues or resonance frequencies and $\mathbf{E}$ are the eigenvectors. For an arbitrary cavity shape, this problem becomes very complex. In general, there is no closed-form solution to (2), therefore electromagnetic simulations are needed to compute the resonance frequencies.

It is noted that applying the curl of the curl identity to the left side of (2) and assuming that there is no free charge, i.e. $\nabla \cdot \mathbf{E} = 0$, we arrive at the wave equation or Helmholtz equation for $\mathbf{E}$

$$\nabla^2 \mathbf{E} - \gamma^2 \mathbf{E} = 0 \tag{3}$$

where γ^2 is given by

$$\gamma^2 = -\omega^2 \mu \left(\varepsilon - j\frac{\sigma_d}{\omega}\right) = j\omega\mu(\sigma_d + j\omega\varepsilon) \tag{4}$$

The Q factor of a resonant mode is an important parameter since it is a measure of the damping, which is directly associated to the losses. A high Q resonant mode of a cavity can be easily excited by the device enclosed and that resonance will persist due to the low losses. The Q factor is defined as

$$Q = \omega \frac{W_T}{P_T} \tag{5}$$

where ω is the angular frequency of the resonant mode, W_T is the average energy stored, and P_T is the total power dissipated in the cavity. The energy stored in a cavity is the sum of the electric energy W_E and the magnetic energy W_M, that can be calculated as

$$W_E = \frac{1}{2}\varepsilon \int_V |\mathbf{E}|^2 dV \tag{6}$$

$$W_M = \frac{1}{2}\mu \int_V |\mathbf{H}|^2 dV \tag{7}$$

The total power dissipated in the cavity P_T is related to the volume losses in the filling dielectric material and the surface losses due to the skin effect in the walls. Thus, P_T is the sum of the power dissipated in the dielectric material P_D and the power dissipated in the walls of the cavity P_W, which are given by

$$P_D = \frac{1}{2}\sigma_d \int_V |\mathbf{E}|^2 dV \tag{8}$$

$$P_W = \frac{1}{2\sigma_w \delta} \int_S |\mathbf{H_t}|^2 dS \tag{9}$$

where σ_w is the conductivity of the walls of the cavity, δ is the skin depth at the resonant frequency ω, and $\mathbf{H_t}$ is the tangential magnetic field at the surface of the walls.

It is noted that the calculation of the Q of a resonant mode requires knowing the electric and magnetic fields, therefore the Maxwell's equations should be solved. As we mentioned before, this is very complex for non-uniform cavity shapes filled with different materials such as the enclosure analyzed in this work. Moreover, volume and surface integrals need to be calculated. For these reasons, the easiest way to obtain the Q factors is performing electromagnetic simulations.

III. ENCLOSURE SIMULATION

To calculate the resonant frequencies and the Q factors we carried out electromagnetic simulations using the 3D model of the enclosure, which is shown in Fig 1. Particularly, we used an eigenmode solver dedicated to simulating closed structures. This solver can determine the resonant frequencies of the structure and the field distribution of the resonant modes.

The enclosure is made of aluminum and its size is approximately 50 mm × 150 mm × 250 mm. In order to obtain accurate results, we included the material characteristics of the substrate of the PCB and the layer stack-up. Moreover, we added the circular connector used for the digital interface. The PCB traces were not modeled because they have a small influence on the resonance frequencies [2]. Table I presents the most relevant resonance frequencies of the enclosure calculated by simulation.

The Q factors of the resonant modes were obtained by performing the loss calculation. Metallic losses, due to the finite conductivity of the enclosure walls, and dielectric losses were considered. Initially, the walls were assumed perfectly conductive; therefore the Q factors were calculated using the perturbation theory considering the conductivity of the aluminum [1] [9].

TABLE I: Simulation results.

Mode	Frequency [MHz]	Q Factor
1	1126.0	4633
2	1505.1	4367
3	1931.3	1010
4	1973.6	2320
5	2012.9	2310
6	2232.5	1144
7	2245.3	2142
8	2479.6	2589

Even very low coupling between the circuits and the high Q resonant modes may disturb the front-end operation. In this way, the simulation results show that there exist resonant modes that should be damped in order to guarantee the proper functioning of the front-end. Other resonant modes are well outside the frequency range of operation of the front-end, hence do not suppose a risk for the receiver.

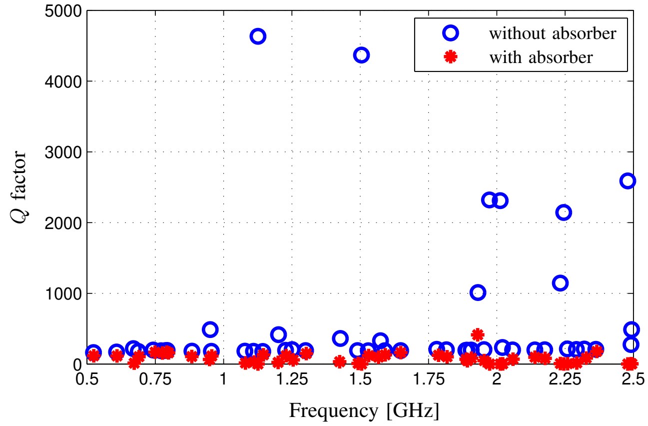


Fig. 2: Simulation results with and without absorber.

IV. Proposed Solution

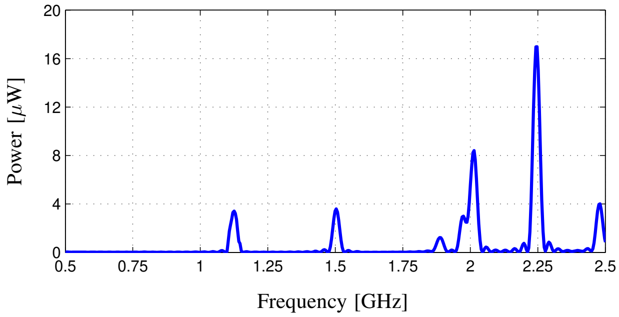
The simulation results presented in the section before show that the problem of the resonant frequencies of the analyzed enclosure should be solved in order to avoid a degradation in the front-end's performance. Considering that the design of the enclosure cannot be modified, some solutions such as placing posts inside the cavity or changing the dimensions of the enclosure are not suitable. Therefore, we propose to use a microwave absorber material to damp the resonances.

An effective absorber for cavity applications has high dielectric or magnetic loss in a wide frequency range. Dielectric absorbers are generally composed of an inexpensive foam coated with carbon, therefore they are electrically conductive. On the other hand, magnetically loaded elastomers are non-conductive. Typically, for the same thickness of material, magnetic absorbers are more effective than dielectric absorbers [8]. However, magnetic absorbers are expensive.

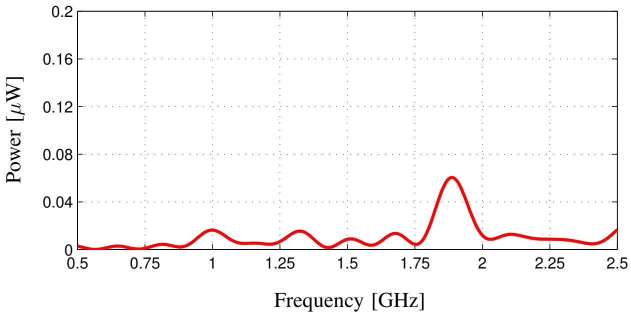
Because of the enclosure considered in this work has a big space between the PCB and the cover, we chose a dielectric absorber, particularly ECCOSORB$^{\circledR}$ LS-26 [10]. In order to increase the performance of the absorber, we use the maximum material thickness available which is 6.35 mm.

Fig. 2 shows the simulations results with the absorber placed on the cover of the enclosure and without the absorber. It can be seen that with the absorber located inside the cavity a high reduction of the Q of the resonant modes is achieved in wide frequency range.

To assess the effect of the reduction of the Q of the resonant modes on the front-end's performance, we carried out a simulation to estimate the coupling between the antenna inputs with and without the absorber. In particular, we simulated the power captured by each antenna input due to the contribution of the others, i.e. the power coupling. The obtained results for the antenna input 1 are shown in Fig. 3. As it can observed in Fig. 3a, the peaks in the power captured correspond to the main resonant frequencies of the enclosure, which are listed in Table I. These peaks evidence a deterioration in the isolation between the channels. Fig. 3b shows that the absorber placed on the cover of the enclosure reduces the power captured by the antenna input about two orders of magnitude. This implies a high improvement in the isolation between the channels and confirms the viability of the proposed solution. It is important to highlight that similar results were obtained for the rest of the channels.



(a) Without absorber.



(b) With absorber.

Fig. 3: Simulated power captured by the antenna input 1.

V. Measurement Results

In order to verify the effectiveness of the absorber, the isolation between the adjacent channels of the front-end was measured with and without the absorber material. To determine the isolation, we drove the input of the channel N with tones of power P_{IN} at 1575.42 MHz and 1227.6 MHz, that correspond to the center frequencies of the L1 and L2 bands respectively. Then, we measured the coupling power P_{OUT} at the output of the adjacent channel $N+1$ using a spectrum analyzer. The output of the channel N and the input of the channel $N+1$ were terminated with 50Ω loads. Finally, the isolation between channels N and $N+1$ is calculated as

$$L[\text{dB}] = P_{IN}[\text{dBm}] - P_{OUT}[\text{dBm}] + G[\text{dB}] \tag{10}$$

where G is the total gain of the channels of the front-end.

First, we measured the isolation without the absorber. Then, the LS-26 material was bonded to the inner side of the cover by means of an adhesive transfer tape that can tolerate high temperatures. Table II presents the obtained results for the L1 and L2 bands. It can be noted that without the absorber the isolation between some channels is below the value needed for the correct operation of the front-end, which is 40 dB. As expected, the absorber improves the isolation allowing to satisfy the design requirement. Indeed, the implemented

TABLE II: Measurement results with and without absorber.

Adjacent channels	**Without absorber**		**With absorber**	
	L1	**L2**	**L1**	**L2**
1-2	38 dB	43 dB	51 dB	57 dB
2-3	47 dB	29 dB	47 dB	43 dB
3-4	34 dB	26 dB	53 dB	41 dB

solution increases the isolation between adjacent channels up to 19 dB.

Finally, it is worth to mention that the presence of the absorber material has a small influence on the other characteristics of the front-end, such as gain and noise figure. This confirms the viability of the proposed solution.

VI. CONCLUSIONS

We calculated the resonance frequencies of the enclosure of a multichannel RF front-end and we found high Q resonant modes near the frequency band of operation. Simulations carried out demonstrated that the resonant modes of the enclosure increase the coupling between the RF channels, which can affect the front-end functioning. In order to avoid a degradation in the performance of the front-end, we used a dielectric absorber for damping the resonances. The effectiveness of this inexpensive solution was verified by simulation and measurement.

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