Interaction of Active MMIC with Package/Housing

Ashish Sarvaiya*, [1], Sanjeev Gupta[2], Deepak Ghodgaonkar[3],

[1]Government Engineering College, Bhavnagar, Gujarat, India
[2, 3] Dhirubhai Ambani Institute of Information and Communication Technology, Gandhinagar, Gujarat, India
*corresponding author, E-mail: aks.sarvaiya@gmail.com

Abstract

This paper presents enclosure effect comprehensive by 3D electromagnetic modeling, simulation and measurement of active MMIC with package/housing. When put inside a test box or package with a cavity, MMIC shows significant deviation from it RF On Wafer (RFOW) measurement data. Cavity resonance"s adverse effects were analyzed by eigen mode solver using CST Microwave Studio and RFOW measurement and in test box data was matched by simulating package/house with the best suited RF absorbers.

1. Introduction

Monolithic Microwave Integrated Circuit (MMIC) widely deviates from its on-wafer and in the package performance. It is recommended that MMICs be tested in their package as well as subjected to the on-wafer RF characterization. Package/housing design requires prior adequate knowledge of RF field distribution inside the package/housing. Package/housing performance degrades at high frequency mainly because of the ring resonance and cavity resonance. Ring resonances occur when stray electromagnetic fields couple with the ceramic frame of the package [1, 2]. Cavity resonances occur when the volume enclosed by the package behaves as a rectangular metal cavity [3]. Ring resonance can be eliminated as reported in [1, 2, and 3]. In cavity resonance, the conductive surface of the enclosure supports several resonant modes which induce surface currents on walls of the packages. These surface currents may result in catastrophic failure of device. Hence, to derive systematic methodology for comprehensive analysis of the package/housing effect is one of the prime requirements for stable MMIC design for different applications.

A properly designed package should have only a small effect on the circuit. Resonant modes in the operating band must be damped by lowering the associated Q of the package or by suitably designing the circuit layout. A common technique for reducing the coupling to a resonant mode is to place a microwave absorber on the cover. A conventional microwave absorbers composed of materials with bulk resistive properties may be placed in the package as has been done by Hallford and Bach [4]. Resonant modes of rectangular metal package may be damped by fixing thin resistive film of a dielectric substrate with high dielectric constant value to one of its wall which is similar approached used in Jaumann absorber [5]. Williams [6] suggested using a dielectric substrate coated with a resistive film as an inexpensive alternative to the microwave absorber. Armstrong and Cooper [7] experimentally investigated the use of microwave absorbing materials to suppress the coupling to resonant modes. Jansen and Weiner [8] developed circuit"s models for microstrip discontinuities in an enclosure, but their use when a lossy material was present has not been verified. John and Robert [9] used moment of method formulation which models microstrip circuits in a lossy enclosure using rooftop currents. They have investigated the coupling of power to a resonant mode as a function of circuit location in an enclosure. Robert [10] used the side wall images to compute the package effects in Method of Moments (MoM) analysis of MMIC circuits. Robert [10] described formulations to calculate a circuit„s terminal characteristics, with and without a lateral enclosure and his approach suits mostly for low Q enclosure.

For accounting the radiation produced by the different circuits in the package and to design package with reduce size, weight and cost, full wave electromagnetic simulation design tools must be used. Several full wave techniques have been developed to analyze MMIC circuits in an enclosure. These techniques are generally based on the MoM, Finite Element Method (FEM) and Boundary Element Method (BEM). These techniques have high efficiency but confined to a limited number of simple geometries. The behavior of packaged with single and coupled MMIC via-hole grounds has been investigated by using a graded mesh FDTD code running on massive parallel computer [11]. Another full wave analysis of packaged microwave circuits with active and non linear devices using FDTD technique was presented [12]. With package and without the package analysis of circuit was carried out [12]. Developing the CAD tool for designing optimum package of MMIC was demonstrated [13]. The method for eliminating cavity resonance and equivalent circuits for EMI prediction were presented [14-16]. The studies on shielding effectiveness of metallic cavities with apertures were discussed [17-20]. The papers [21, 22] described the fractional square and rectangular cavity resonator. In [23], modeling and analysis of the package and different mitigation techniques were used to make stable, resonance free microwave amplifier for a C-band space borne SAR payload. The electromagnetic simulation and characterization of the metal ceramic package for packaging of high isolation switches was performed [24].

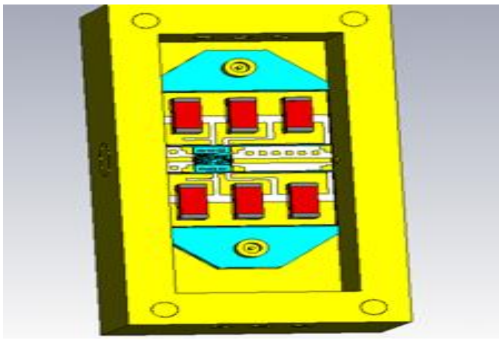


Figure 1: Model of actual Test Box with LNA MMIC

This paper describes the interaction of active MMIC chip performance with package/housing comprehensively. In this paper, Section I describes the experimental test case of Low Noise Amplifier (LNA) with package/house having enclosure effect. The 2.5D electromagnetic analysis of LNA was carried out using Advanced Design System (ADS) Software. We have circuit simulation, RFOW measurement and in test box test data of MMIC. We have compared circuit simulation, RFOW measurement and in test box test data of MMIC. Circuit simulation and RFOW measurement matches nicely but test box test data differs considerably which is presented in Section I. As ADS Software does not account enclosure effect comprehensively, we have derived systematic methodologies for enclosure effect by 3D Electromagnetic modeling, simulation and measurement of active MMIC with Package/housing. We have identified whether any cavity resonance effect was degrading the performance of the MMIC by theoretical way and by using CST Microwave Studio‟s Eigen Mode solver in section 2. Practical mitigation techniques of enclosure effect are discussed in section 3.

2. An experimental test case: LNA having enclosure effect

Analyzing the enclosure effect, Low Noise Amplifier (LNA) MMIC chip was used as a test case which was operated in Ku band with 31 dB gain. LNA MMIC chip was designed at Space Application Centre (SAC) Ahmedabad, India. The 2.5D electromagnetic analysis of LNA was carried out using ADS software. High frequency wafer probe station and network analyzer were used for RFOW measurement. A 2-port network analyzer was used to perform measurements of the packaged/housed LNA MMIC Circuit. We have compared circuit simulation, RFOW measurement and in test box test data of MMIC. As ADS can‟t blend the EM and circuit theory, Simulation and RFOW measurement results matched but test box test data differed considerably. Hence full wave simulation of MMIC chip with packaging and housing is mandatory in design flow. A commercial full wave simulator CST Microwave Studio was used for 3D electromagnetic simulations of the packages under study.

Figure 1 shows the model of test box with LNA MMIC layout designed in ADS Software. The model of test box has also pre and post link cards, biasing cards, carrier plate, package\house, single and multilayer capacitors for dc biasing. MMIC RF on wafer and test box test data is shown in Fig. 1. The gain of LNA MMIC on-wafer was 31 dB but after packaging/housing, the gain reduced to about 27 dB with two dips in the result as shown in Fig. 2. Measured results were with the absorber hence there were only two dips present otherwise many glitches might be observed. Figure 2 results show the presence of cavity resonance effect.

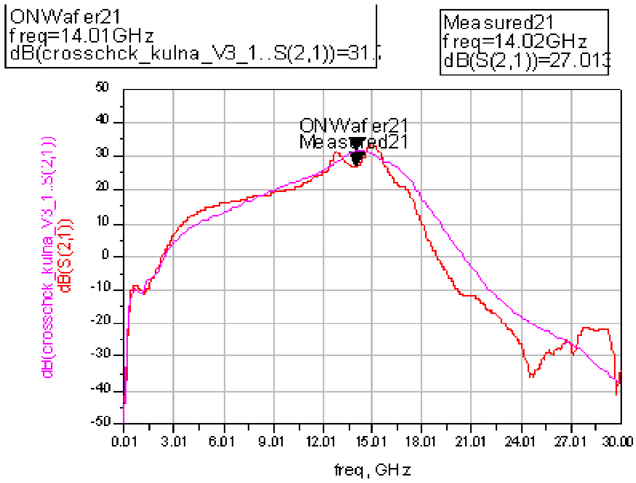


Figure 2: Cavity resonance effect on S21 (Gain of LNA): Comparison of on wafer and measured S21 (dB) with package/housing effects

3. A Cavity Resonance analysis using Eigen Mode Analysis

To understand the cause of deviation in measured and on wafer results, eigen mode analysis of the package structure was carried out using CST Microwave Studio software.

Resonance frequencies of a rectangular microwave cavity for any TE_{mnl} or TE_{mnl} resonant mode can be found by imposing boundary conditions on electromagnetic field expressions. This frequency is given by

$$f_{mnl} = \frac{2}{2\sqrt{\mu_r \varepsilon_r}} \sqrt{\left(\frac{m}{a}\right)^2 + \left(\frac{n}{b}\right)^2 + \left(\frac{l}{d}\right)^2}$$

where m, n, l being the mode numbers and a, b, d being the corresponding dimensions; c is the speed of light in vacuum; μ_r and and ε_r are relative permeability and permittivity respectively. Theoretical eigen frequencies are calculated using above equation which are mentioned in table 1.

For eigen mode analysis of the package structure, different cases are presented with results in Table 1.Case A is unassembled cavity. Case B is Package with Carrier plate only. In this case there is an absence of all other circuits except the package and carrier plate. Case C is model test box with LNA MMIC and all necessary circuits. The results show that in case A, unassembled cavity has almost identical resonance values with eigen mode solver for cavity size

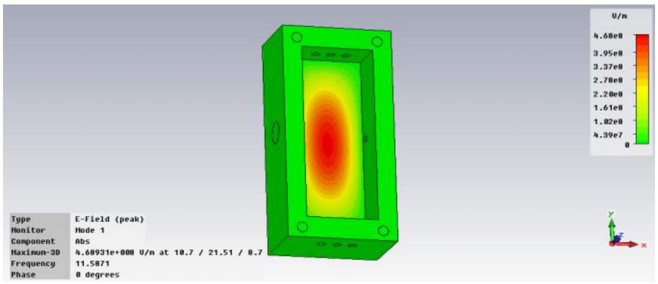
Table 1. Different Cases: Eigen mode analysis results for (a) unassembled cavity structure (b) Package/house with carrier plate only and (c) Actual Test box with LNA MMIC. The result indicates that 11.45GHz and 14.50GHz resonance peaks degrade the performance of LNA MMIC.

Different Cases	**Case A: Unassembled cavity structure**		**Case B: Package with carrier plate only**	**Case C: Actual test box with LNA MMIC**
Cavity having different modes	**Theoretical eigen frequency (GHz)**	**Eigen mode solver eigen frequency (GHz)**	**Eigen mode solver eigen frequency (GHz)**	**Eigen mode solver eigen frequency (GHz)**
Mode 1	11.60	11.58	11.31	08.15
Mode 2	13.76	13.74	12.96	11.45
Mode 3	17.8571	16.71	15.48	14.60
Mode 4	18.361	18.32	18.87	17.10
Mode 5	19.79	19.75	20.39	20.22

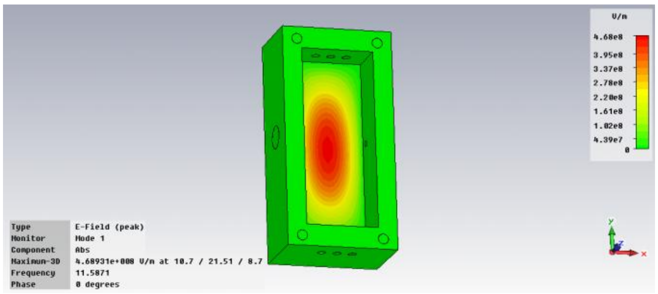
dimension 13.9× 35.1× 8.4 mm. It was also found that theoretical eigen resonance frequency and internal cavity structure was not free of resonances up to 18 GHz, with the lowest mode occurring at 11.60 GHz. The presence of dielectric material (such as MMIC chip, DC capacitors and other interconnect lines), known to be detrimental for resonance situations, was also simulated by incorporating the carrier plate into the cavity, as shown in Table 1. Simulation result indicates an early onset of resonance with addition of other structures. As evident from the Table 1, the frequency of fundamental resonance is 8.15 GHz, which is well beyond the frequency range of interest but mode 2 and mode 3 having frequency of 11.45 and 14.60 respectively could adverse the electrical performance of the LNA MMIC chip as measured results reported. These results prove that the problem was related to the cavity resonance of the package. Figure 3 shows the E and H Field for mode 1 and mode 2 in an unassembled cavity structure.

4. Post mitigation technique: use of absorbers

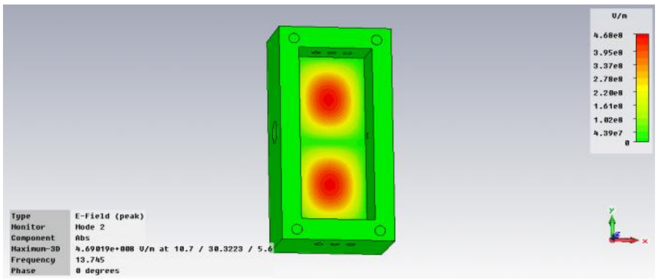
After realizing that package/housing box exhibits enclosure effect that degrades the performance of LNA MMIC circuit, it is required to use post mitigation technique. One of the widely used technique is to use the RF absorber. There are many types of absorbers available but the most effective absorbers for cavity resonance dampening are magnetically loaded with iron or ferrites.These materials are characterized by high permittivity and permeability plus a high magnetic loss. The energy will tend to reside inside the material whose permittivity/permeability is high (and hence away from your circuit). The high absorption will lower the Q of the cavity and hence the magnitude of the VSWR. We have used ECCOSORB absorber type SF-11.0-18.0 GHZ which is placed on full cover as shown in Fig. 4. Circuit simulation was performed using ADS Software and 3D fullwave transient S-parameter simulation was performed using CST MWS Studio. In Fig. 5, there are three results; LNA gain at 14 GHz is 27.12 dB in ADS simulates result (only chip circuit simulation s(2,1) dB result), LNA Gain is 26.81 dB in 3D CST transient simulated S-parametes S(2,1) result when box having cover or lid (Red color) and it exhibits an enclosure effect (Red line). There are many spikes (Red line) which manifest the exhibition of enclosure effect in package/house. As we have placed rf absorber inside the lid (back side of top cover) of ECCOSORB absorber type SF-11.0-18.0 GHZ, The spikes dilute and encloser effect was removed as shown in Fig. 5 (Blue line).



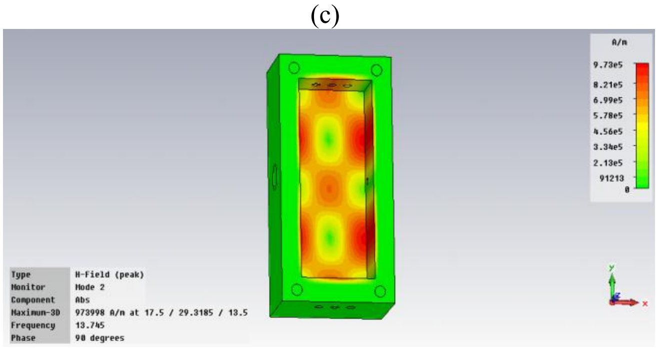
(a)



(b)



(c)



(d)

Figure 3: Eigen mode simulation in unassembled cavity: a) Mode 1 E field b) Mode 1 H Field c) Mode 2 E-field and d) Mode 2 H-Field

5. Conclusion

We have successfully analyzed cavity resonance problem. We have simulated the test box and RFOW measurement and in test box data is matched by selecting proper absorber with help of full wave simulation.

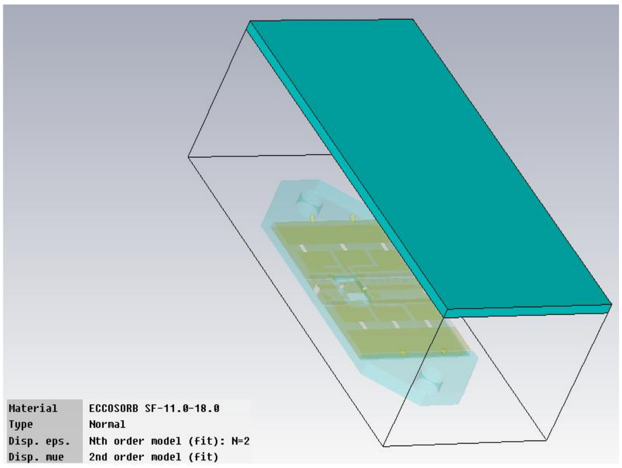


Figure 4: Absorber placed inside the lid that dilutes the cavity resonance effect.

Figure 5: Red spikes seen as results of the Cavity resonance effect in the housed circuit; Blue spikes indicate that use of the absorber dilute the effect of cavity resonance

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