Prediction of Near-Field Shielding Effectiveness for Conformal-Shielded SiP and Measurement with Magnetic Probe

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***Abstract*—This paper presents a fast prediction method to evaluate the near-field shielding effectiveness (SE) for conformal-shielded System-in-Packages (SiP). By revising the typical EM method to meet SiP circumstances, the near-field SE can be quickly estimated. A simple conformal-shielded SiP module is designed. To experimentally verify the proposed method, two kinds of metallic shielding materials, copper and nickel, are sputtered on the module with different coating thicknesses. In the near-field, the measured SE reaches up to 52 dB for 4-µm copper coating as well as 54 dB for 15-µm nickel coating. The predicted results are closely agreed with simulations and measurements from 0.01 and 1 GHz.**

Keywords—shielding effectiveness (SE); conformal shielding; System-in-Package (SiP)

I. INTRODUCTION

Current trends in the electronic products are small size, low weight and multi-functions. The System-in-Package (SiP) module provides a highly integration for system design. In spite that SiP may cause severe electromagnetic interference (EMI) problems with high-speed digital circuits [1]. Up to now, shielding lids are used to solve EMI problems in SiP; however, heavy weight and additional assembly are critical defects. Recently, conformal shielding has been extensively investigated to replace shielding lids [2], [3]. Compared with shielding lids, conformal shielding technology not only owns the advantages of space saving and light weight, but also maintains comparable shielding performances.

As usual, the shielding capability of metallic sheet is evaluated by shielding effectiveness (SE). The value of SE depends on the shielding material, the operating frequency, and the characteristics of the incident EM field, which belongs to near- or far-field region. The EM method which solves Maxwell equations through boundary conditions is classically utilized to estimate the SE [4]. In the previously works, an infinite shielding sheet were assumed and a uniform plane wave propagates within the free space. Since the circumstance hardly meets on SiP modules, the EM method has to be modified. In this paper, a fast estimation based on the EM method evaluates the SE of conformal shielding on SiP. In the near-field, it is much more complicated for estimating the SE on SiP modules than far-field condition. To simplify the problems, with some applied assumptions, the EM method still can evaluate the SE on SiP approximately.

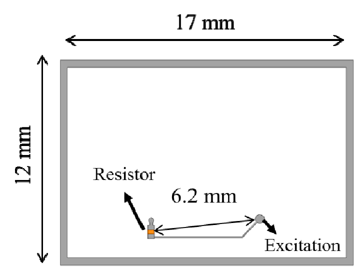

Fig. 1 Straight-line pattern is terminated with a resistor as the radiation source.

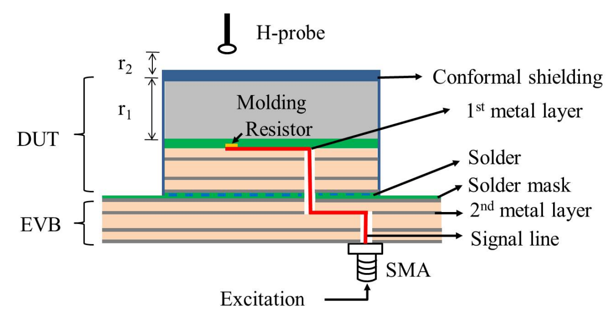

Fig. 2 Overall structure of the test sample.

II. DESIGN OF TEST SAMPLES AND ANALYSIS

A. Design of Test Samples

In order to estimate the SE for the conformal shielding on SiP, a test sample is designed for broadband testing. The layout of radiation source is shown in Fig. 1. The size of the DUT is 12 × 17 mm^2. To achieve broadband match and reduce reflection power of measuring equipment, the characteristic impedance of meander line is designed as 50 Ω and terminated by the matched resistor. To realize the structure, the cross-section of test sample is demonstrated in Fig. 2. The test

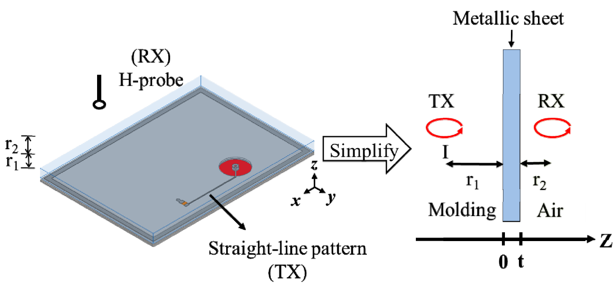

Fig. 3 Schematic of the proposed structure in the near-field.

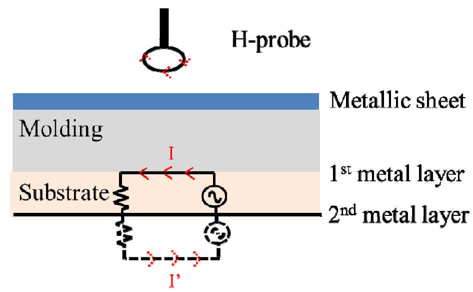

Fig. 4 Coplanar loop antenna orientations.

sample is composed of the device under test (DUT) and the evaluation board (EVB) — solders are used to connect each other. Both of the DUT and the EVB have four metal layers to strengthen the board hardness. For the DUT, the layout of straight-line is placed on the top metal layer (1^{st}) as an antenna.

Since the DUT is too small to directly interconnect with a SMA connector, it is inevitable to utilize the EVB. For feeding power to the DUT with small leakage, a well-designed EVB is necessary. For the EVB, a 50 Ω strip line is designed in 2^{nd} metal layer to reduce the power leakage of signal trace. The size of the EVB is 19.5 × 29.5 mm^2. To realize conformal shielding, a thin metallic sheet is coated on the top and the sidewall of the DUT with sputtering technology.

B. EM Method with Complex Wave Impedances

The schematic of near-field shielding mechanism in SiP can be simplified and illustrated in Fig. 3. The layout pattern of straight-line is the radiation source noted "TX", whereas the magnetic probe is considered as the receiver named "RX". The conformal shielding is well connected to the circuit ground; therefore, it can be seen as an infinite metallic sheet. The TX wave propagates in the molding and then incidents to the metallic sheet. At last, the TX wave penetrates off the metallic sheet and is received by the RX termination. Due to the tiny packaged size, the TX and RX, in the near-field region, are considered as complex wave impedances.

In the near-field, the assumption of uniform plane wave is kept to simplify the problem [5]. Then, SE can be solved by Maxwell equations through boundary conditions at z = 0 and z = t. Then, the ratio of incident and transmitted waves can be represented as

$$\frac{\vec{E}_i}{\vec{E}_t} = \frac{(\eta+Z_1)(\eta+Z_2)}{4\eta Z_2} e^{\gamma t} e^{-j\beta_0 t} [1 - \frac{(\eta-Z_1)(\eta-Z_2)}{(\eta+Z_1)(\eta+Z_2)} e^{-2\gamma t}] \,. \quad (1)$$

The Z_1 and Z_2 indicate the wave impedances of TX and RX. Respecting the fact that the shielding material is normally a good conductor, the propagation constant (γ) and the equivalent characteristic impedance (η) are approximately expressed as

$$\gamma \approx (1+j)\sqrt{\pi f \mu \sigma} \,, \quad (2)$$

$$\eta \approx \sqrt{\frac{j2\pi f \mu}{\sigma}} = \frac{\gamma}{\sigma} \,, \quad (3)$$

where μ and σ are the permeability and conductivity of the shielding material, respectively. Then, SE is generally defined as the ratio of the incident transverse field to the transmitted transverse field in decibels [4]. The expression can be defined as

$$SE_{dB} = 20\log_{10}\left|\frac{\vec{E}_i}{\vec{E}_t}\right| \,. \quad (4)$$

Furthermore, the radiation mechanism of proposed samples is illustrated in Fig. 4. According to the image theory, the currents flow on the 1^{st} metal layer and its effective image current forms a current loop. Since the height of 2 layer substrate in DUT is small enough compared with the corresponding guided wavelength, it can be considered as a small loop antenna. On the other hand, the magnetic probe (H-probe) will be motivated the induced current which also can be considered as a small loop antenna. As a result, the scenario of proposed structure can be regarded that two loop antennas are in the same plane and perpendicular to the metallic sheet which namely coplanar loop antenna orientations [5]. Thus, the wave impedance of small loop antenna can be also described as [4]

$$Z_i = -\frac{\eta_0}{\sqrt{\varepsilon_{r,i}}} \frac{j/\beta_i r_i + 1/(\beta_i r_i)^2}{j/\beta_i r_i + 1/(\beta_i r_i)^2 - j/(\beta_i r_i)^3} \,, \quad (5)$$

where η_0 is the intrinsic impedance in free space, $\varepsilon_{r,i}$ is the relative permittivity, β_i (= $\omega\sqrt{\varepsilon_{r,i}}/c_0$) is the phase constant of the propagating media, and r_i is the distance from TX or RX to the metallic sheet. i = 1 or 2 means the material characteristics in region I or II. For Z_1, ε_{r1} = 3.8 and r_1 = 0.91 mm. For Z_2, ε_{r2} = 1 and r_2 = 0.3 mm.

III. Measurement Setup and Result Discussion

A. Measurement Setup

A near-field measurement setup is established to evaluate SE of the conformal shielding on SiP as demonstrated in Fig. 5. The instruments include a HP-83650P signal generator, a MITEQ pre-amplifier (0.01-3000 MHz), an R&S FSP40 spectrum analyzer, and a HITACHI EMV-200 magnetic-field scanning machine with the computer-aided software. By automatically controlling the probe, the radiation emissions were scanned with spatial resolution of 1-mm step along both x

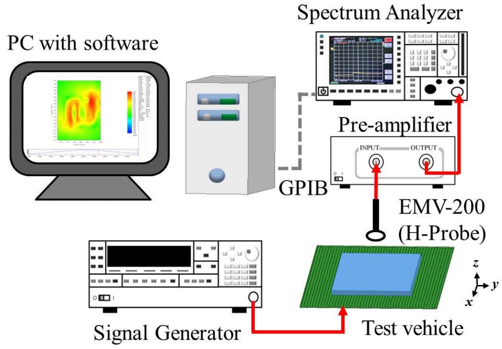

Fig. 5 Measurement setup.

TABLE I
PARAMETERS OF SHIELDING MATERIALS

Relative permeability		
Frequency (GHz)	**Ni**	**Cu**
0.01	12.92 – j 1.14	0.999991
0.03	12.90 – j 1.85	
0.10	9.45 – j 5.85	
0.50	4.63 – j 1.96	
1.00	3.64 – j 3.05	
Conductivity (S/m)	3.3×10^{6}	5×10^{7}

and y directions in the entire area of DUT. Then, SE can be obtained by calculating the differences between the shielded and unshielded DUT in the fix position. For the near-field measurement, the measured SE of metallic sheet (SE_M) is expressed as

$$\mathrm{SE_M}\ (\mathrm{dB}) = 20\log_{10}\left|\frac{H_{unshielded}}{H_{shielded}}\right|. \quad (6)$$

B. Comparison SE Results

In this work, two shielding materials (Cu and Ni) with different shielding thicknesses are investigated. The parameters of shielding materials are listed respectively in Table I. The relative permeability of nickel is measured; however, the permeability is not that high as expected after sputtering process. On the other hand, copper is a good shielding material due to its high conductivity and low cost. As depicted in Fig. 6, the SE of 4-μm copper, 5-μm nickel, 10-μm nickel and 15-μm nickel are shown from 0.01 to 1 GHz. The EM method shows a good consistency with the simulation. In measured results, the deviations are below 10 dB for most of the cases. The reason may cause from the relative permeability of nickel may be not accurate since the results between the EM method and simulation are almost the same. It is notice that the simulation results are obtained from ANSYS HFSS.

To figure out which material is more suitable for shielding, the measured SEs of 4-μm copper and 15-μm nickel are compared as follows. For 4-μm copper, the measured SE of the conformal shielding on SiP is 14, 29, 45, and 52 dB at 0.01, 0.1, 0.5, and 1 GHz, respectively. Furthermore, the measured SE with 15-μm nickel is 16, 39, 49, 54 dB correspondingly at 0.01,

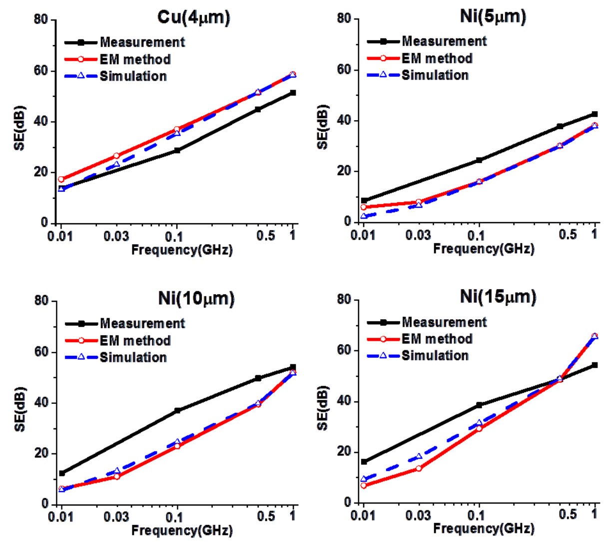

Fig. 6 SE results with different coating materials and thickness.

0.1, 0.5, and 1 GHz. The 4-μm copper has a greater SE than 15-μm nickel. The reason is the relative permeability of nickel is not high enough; however, copper has a ten times of conductivity than nickel. For the purpose of light weight and low profile, copper will be the better choice.

IV. CONCLUSIONS

To evaluate the near-field SE of conformal shielding on SiP, a fast prediction based on the shielding theory is proposed. A straight-line structure loaded with a termination is designed as the radiation source on SiP. With the use of magnetic probe, the near-field SE on SiP is predicted and verified experimentally. The proposed method shows a good agreement compared with simulation and measurement from 0.01 to 1 GHz.

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