The Development of Novel Coaxial Tester on Electromagnetic Shielding Effectiveness Measurement

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***Abstract*—A novel coaxial tester based on the ASTM D4935-2010 standard for shielding effectiveness (SE) measurement of electromagnetic shielding materials in the frequency range from 30 MHz to 6 GHz was proposed in this paper. The critical aspects of different metal materials for the novel tester were discussed. The results of the study demonstrated that Return Loss(RL) parameter and resonance peaks below the cutoff frequency of the tester are dependent on option of materials.**

Keywords—electromagnetic shielding materials; shielding effectiveness； coaxial tester; metal materials;Simulation

I. INTRODUCTION

The parameter SE refers to the ability of electromagnetic shielding materials to reduce the transmission of propagating electromagnetic fields [1]. SE is the most important concern of those materials for both manufacturers and users in EMI field. It can be concluded that there are various measurement methods to measure the SE against far-field or near-field sources and some papers also illustrate clearly these methods' advantages and limitations [1-5], as one of most used methods, flanged coaxial tester in ASTM D4935-2010 standard [6] has been adopted to investigate the electromagnetic shielding for frequency range from 30 MHz to 1.5 GHz. The standard method is focused on far-field SE measurements, and its main technique is based on the theory of mono-mode TEM wave in coaxial transmission line.

According to ASTM D4935-2010 standard, flanged coaxial tester can be used to measure the SE of planar electromagnetic shielding materials in desired frequency range, with advantage of well repeatability and good dynamic range. The main disadvantage of the tester is the narrow frequency band of operation, of which method is only valid over a frequency range of 30 MHz to 1.5 GHz that cannot satisfy the need of broader frequency range nowadays. Hence, Maria Sabrina Sarto [4] presented innovative coaxial tester in a wider frequency range up to 8 GHz and Horacio Vasquez [5] developed a simple coaxial tester to higher frequencies (up to 13.5 GHz). However, ASTM D4935-2010 standard states that flanged coaxial tester will call for electrically thin materials, the thickness of materials under test are associated with cut-off frequency. Considering some thicker material, we control the frequency in reasonable range and determine the upper frequency limit 6GHz.

The primary objective of this paper is to present a novel flanged coaxial tester in broadband frequency range up to 6 GHz, and to evaluate the RL data of this novel tester by using of different types of metal materials for coaxial conductor in simulation. The results caused by different metal materials were analyzed and compared. After simulation, a manufactured tester was developed, which was much simpler and lighter than that of ASTM D4935-2010 standard offers. The simulated S parameters (RL) of the novel manufactured coaxial tester are compared with those obtained from simulation model in the desired frequency range.

II. DEVELOPMENT OF NOVEL COAXIAL TESTER

A. Dimension of Novel Coaxial Tester

We have build up a sketch of novel coaxial tester in broadband frequency range up to 6 GHz. It is combined with N-Type connector, tapering transition and the flanged holder as Fig.1 shows.

The first step is to calculate the dimension of the novel tester, and we have discuss the derivation of formulas for dimension of coaxial tester [7], here we quoted that

$$r_1 = (c_0 / \pi f_c)\left(1 + e^{2\pi Z_0/\eta_0}\right) \quad (1)$$

$$r_2 = (c_0 / \pi f_c)\left(1 - 1/(1 + e^{2\pi Z_0/\eta_0})\right) \quad (2)$$

where：

Z_0 is characteristic impedance of coaxial transmission line;

c_0 is light speed；

f_c is cut-off frequency of TE_{11} wave;

η_0 is wave impedance in vacuum, approximately equal to 377Ω;

r_1 is radius of inner conductor of coaxial tester;

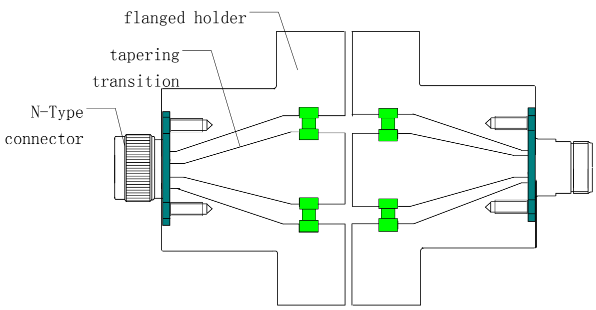


Fig. 1. The sketch of novel flanged coaxial tester

r_2 is the inner radius of the outer conductor of coaxial tester.

According to theory of transmission line, only the dominant TEM wave propagates in the coaxial tester, so f_{max} must be lower than the cutoff frequency f_c of the TE_{11} mode. As C.C Chen [7] recommended, We can get

$$f_{\max} = 6\text{GHz} \tag{3}$$

$$f_c = 1.1 \times f_{\max} = 6.6\text{GHz} \tag{4}$$

Combined (4) with (1), (2), the novel dimensions of the improved flanged holder up to 6GHz are as follows

$$r_1 = 4.4\text{mm}$$
$$r_2 = 10.1\text{mm} \tag{5}$$

Characterized by $Z_0 = 50\Omega$, $\eta_0 = 377\Omega$, $c_0 = 3\times10^8\text{m/s}$.

B. Simulation of Novel Coaxial Tester

To maintain 50Ω impedance throughout the whole coaxial tester and keep RL data of the tester less than 1.2, three-dimensional full-wave numerical simulations are performed. It can be used to assess the effects on the desired dimensions of the coaxial tester. We normally choose Perfect Electric Conductor (PEC) materials as ideal conductor in simulation, which exhibits same value 1 of relative permittivity and relative permeability, and value of infinite bulk conductivity (with 0Ω impedance).So PEC do not produce losses and show the minimum RL data at any frequency point.

Fig.2 shows the simulation model and Fig.3 presents the RL curves of the simulated results. In the beginning, we

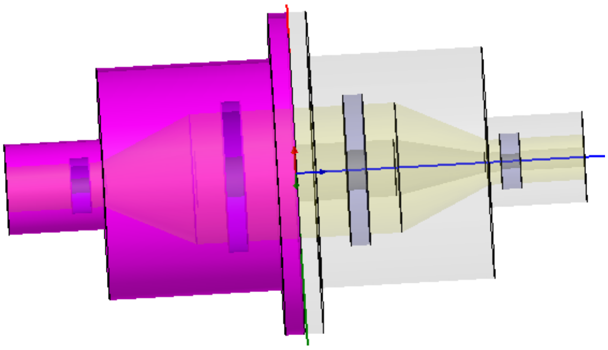


Fig.2. Model of novel coaxial tester

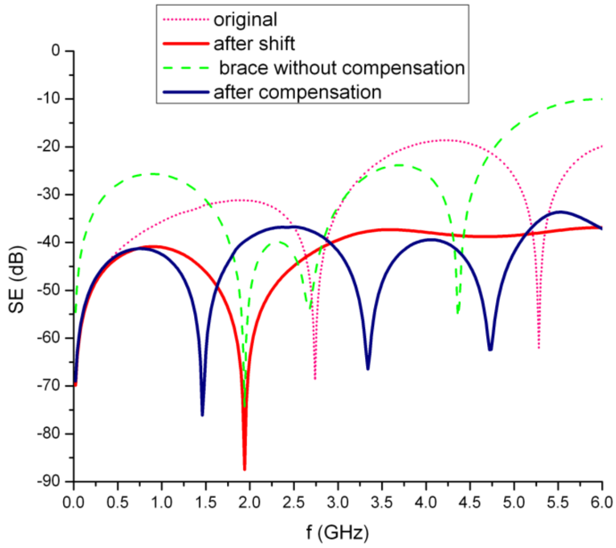


Fig.3. Development of simulated coaxial tester

established a coaxial line without any brace mediums, thus TEM waves can propagate without any rejection and we get an ideal RL data as red solid curve shows Poor RL data obtained as green dash curve shows after bringing in brace mediums, which were used to hold inner conductor and outer conductor of coaxial tester. The reason causing loss so much is that there are discontinuities at the interfaces of N-Type connector, tapering transition and the flanged holder, which lead to impedance mismatch.

Capacitive and inductance compensation methods used to validate the experimental tester were introduced in earlier research work by C.C. Chen and various simulation procedures were carried to compensate the tester, finally we can get the optimal performance of tester and its RL data as blue solid curve shows in Fig.3.

In addition, several resonance peaks appear at 1.46GHz, 3.3GHz and 4.68GHz. According to Perry F.Wilson, this may due to aperture resonances. Using λ as the total length of tester($\lambda = 130\text{mm}$), then resonances would occur at the multiple of 1.125GHz, which correspond to $n\lambda/2$ and $(n+1)\lambda/2$, relatively.

III. MATERIAL SELECTION FOR NOVEL COAXIAL TESTER

Considering of coaxial tester needs to have the characteristics of high mechanical strength, high conductivity and good repeatability, we should choose ideal metal materials in processing, to effectively improve the performance of tester.

C Choice of metal material

Though PEC material is an idealization, in manufacture, we have to choose other metal materials as coaxial conductors because PEC does not really exist. Two different types of metal materials including copper and steel-stainless were selected to replace PEC, as conductor. The specifications and

TABLE I. SPECIFICATION AND CHARACTERISTICS OF VARIOUS METAL MATERIAL

Table Head	Table Column Head		
	Relative permittivity ε_r	***relative permeability*** μ_r	***bulk conductivity*** σ (S • m^{-1})
pec	1	1	1e+030
steel-stainless	1	1	1.1×10^{6}
copper	1	0.99991	5.8×10^{7}

characteristics of those materials are: relative permeability, relative permittivity and bulk conductivity. The values of those specifications for PEC, copper and steel-stainless were listed in Table Ⅰ (the data comes from HFSS library).

In this paper, it expressed copper and steel-stainless' properties comparatively to those of PEC. Here we discuss and analyze the influences of these three different metal materials for coaxial tester.

1)The RL data of different metal materials: For different metal materials, the RL data obtained perform similarly at microwave frequency band but quite differently in low frequency band (as fig.4 a) shows).This is caused by skin depth. Regard the novel tester as a coaxial line, in which TEM wave propagates. The skin depth of a conductive media is defined as the equation

$$\delta = \frac{1}{\beta} = \sqrt{\frac{2}{\pi\mu\sigma}} = \frac{1}{\sqrt{\pi f \mu\sigma}} \tag{6}$$

Where:

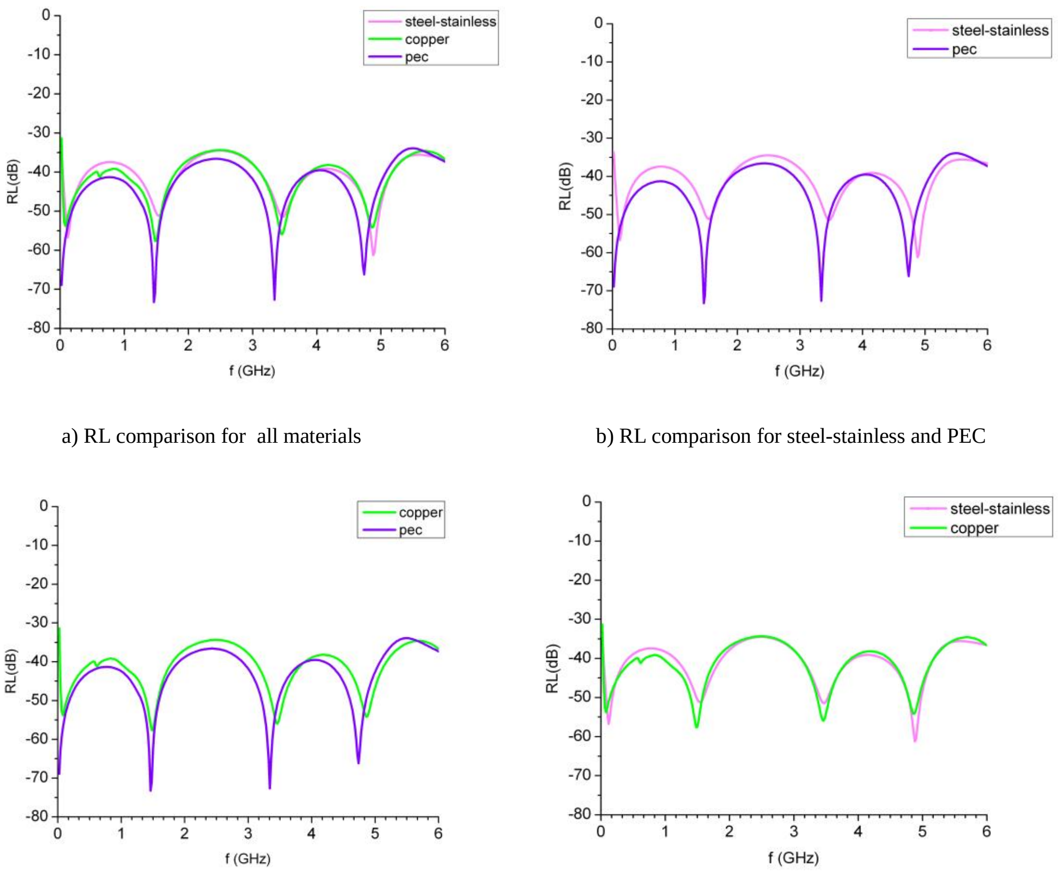
δ is skin depth,

f is frequency

σ is the conductivity

μ is the permeability

According to (6), δ is related to *f*, μ and σ. For the same kind of material, RL curve performs better in high frequencies than low frequencies. The main reason is that skin depth δ is far less in high frequencies than that of low frequencies.



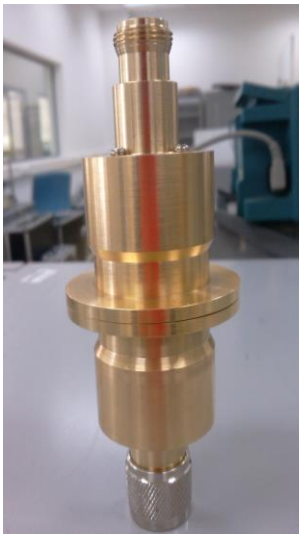
a) RL comparison for all materials

b) RL comparison for steel-stainless and PEC

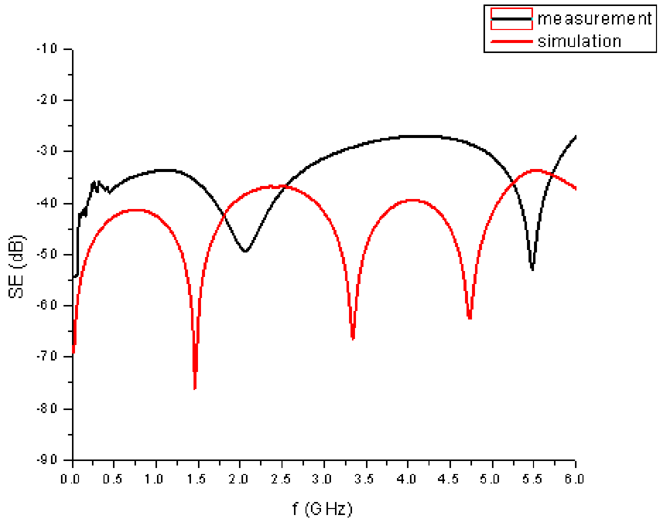
c) RL comparison for PEC and copper

d) RL comparison for steel-stainless and copper

Fig.4. RL of novel tester caused by different metal materials



a)Self-Manufactured tester



b) RL comparison of simulation and measurement

Fig.5. Self-Manufactured tester and RL comparison

2)The influence of bulk conductivity: Now we focus on the comparison between two types of conductive of materials. For metal materials, bulk conductivity is the dominant factor. There are same value 1 of relative permeability and relative permittivity for both.Fig.4 b), Fig.4 c) and Fig.4 d) indicate that resonance peaks shift left due to the increased bulk conductivity.Fig.4d) shows not that apparently because the bulk conductivity of steel-stainless and copper are at same order of magnitude. At low frequencies, The RL data accelerate its degradation rapidly below 20MHz, which depends very much upon the parameter of bulk conductivity the material used.

IV. Manufacture and Measurement of the Tester

Fig.5 a) presents the picture of manufactured tester, which consists of two identical parts that are clamped together by guide rail, to keep the testing materials on flanged holder. The manufactured tester was simpler and easier to manipulate by users.

It can be observed that the maximum difference of RL data is about 7 dB for manufactured tester and simulated tester. Ideally the measured RL data should be consistent with the

TABLE II. The influence factor of electrical

Table Head	Table Column Head		
	Ideal condition	***Actual condition***	***The reason of difference***
characteristic impedance	$(Z_0 \pm 0)\Omega$	$(Z_0 \pm X)\Omega$	Discontinuity of interface
VSWR	1.0dB	>1.0dB	Electromagnetic wave reflection caused by discontinuity
Contact resistance	0Ω	$>0\Omega$	Contact interface and material properties

simulated RL data. In fact, the measured data is affected by two important factors below:

1) modern processing technology: the processing technology nowadays cannot produce actual tester as perfect as simulation one, such as the uneven surface of two flanged holder, the wear of manufactured materials, improper assembly are all factors lead to mismatch impedance.

2) electrical performance: Table II lists the electrical performance of tester in ideal situation and actual situation, and shows the reason of these differences why generate electromagnetic wave reflection, which illustrate the deviation of these two situations clearly.

V. Summary

This research work realized to establish the sketch of a novel flanged coaxial tester for electromagnetic shielding measurement from 30MHz to 6GHz. Due to metal materials have different types of permittivity, permeability and conductivity, the work preformed to compare and analyze the differences of return loss for novel flanged coaxial tester by using various metal materials in simulation, respectively..

In the end, a new tester based on simulated model was manufactured. It compared the measured RL data with that of simulated and analyzed the causes of differences.

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