A Reduction method of Undesired Radiation from the Split Ground Structures (SGS)

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***Abstract*—**The split ground structure for microstrip structure can be used to protect analog/RF signal from SSN interference of digital circuits on PCB with common ground. However, the split ground structure gives rise to undesired emissions that may interfere with nearby circuitry due to the ground discontinuity. In this paper, we have proposed the modified structure, Dumbbell shaped SGS and the method to reduce the radiation by adding the lumped resistor on the proposed Dumbbell shaped SGS.

***Index Terms*—**SGS (Split Ground Structure), SSN, EMC.

I. INTRODUCTION

Recently, the digital and analog/RF circuits have been packaged on single Printed Circuit Board (PCB) with common ground for the several reasons in many digital communications. However, since the high speed digital circuits using CMOS tend to produce significant simultaneous switching noise (SSN) levels and generally digital signal contains several spurious harmonic frequencies, they may interfere with main signal of analog or RF circuits when the common ground is used [1]. The high frequency harmonic and non-harmonic components are seldom specified on the assumption that they can be eliminated using conventional EMC techniques such as filtering, grounding and isolating. The high frequency radiation and interference problems due to ground resonance are often discovered during the system EMC and crosstalk measurement. The ground resonance issues must be addressed at early design stages. Otherwise, expensive and time-consuming design iterations are necessary to solve this problem. The method for this problem to split their ground by slot on ground plane was proposed [2]. It makes isolation for AC between digital and analog/RF circuits while leaving only a small DC connection to maintain a common reference potential.

In this paper, we propose the Split Ground Structure (SGS) [3] as a solution to protect the main signals of analog or RF circuits from SSN interference of digital circuits due to common ground. Even if the basic SGS can be a good solution for SSN problems, it gives rise to undesired emissions that may interfere with nearby circuitry. Therefore, we propose a modified structure, Dumbbell shaped SGS, to reduce radiation of the undesired Electromagnetic field in high frequency range while maintaining good isolation between the digital and analog/RF circuitry. It can reduce the radiation due to third harmonic frequency more than the fundamental frequency. Also, we have suppressed the radiation due to the fundamental frequency by adding the lumped resistor on the proposed Dumbbell shaped SGS. The results of this paper can be applied to the design of Printed Circuit Board using the high speed mixed signals to improve the EMI characteristic.

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II. MODELING AND CHARACTERISTIC

Fig. 1 shows the three-dimensional schematic of the basic SGS for microstrip structure. A ground split slot transversal to a signal trace, introduces a discontinuity for the return current (Fig. 1). The current in the ground plane has to go around the split slot at low frequencies. This current loop introduced by the ground slot will add in as an inductance (L). On the other hand, sufficiently high frequency components will jump as displacement current through the capacitance (C) present underneath the trace and cross the slot and will not even see the inductance. At intermediate frequency range some portion of the current will loop around the slot and some will cross the slot through the distributed capacitance between the edges. To model this behavior, inductance at the low frequency and capacitance at high frequency, the slot can be viewed as a slot transmission line [3].

The equivalent modeling for SGS is represented in Fig. 2. It has same characteristic with the parallel resonant circuit as show in Fig. 3. The general transmission characteristic (S21) of the basic SGS is like as Fig. 3.

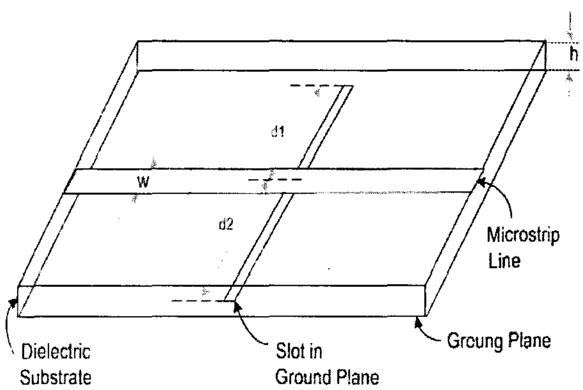

Fig. 1 3-D view of basic SGS

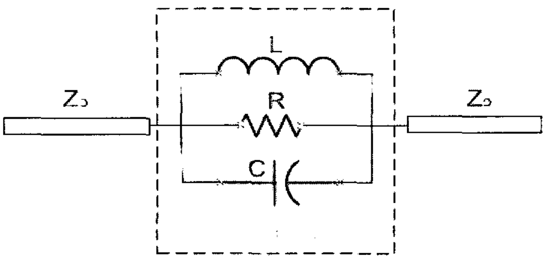

Fig. 2 Equivalent Model

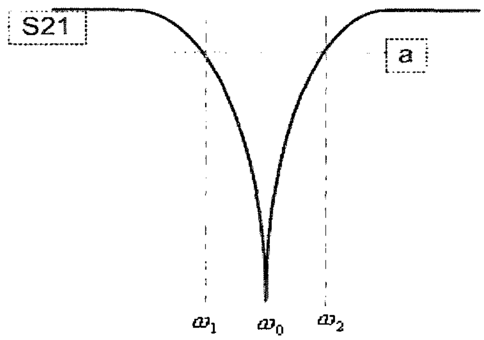

Fig. 3 Characteristics, S_{21}

From the parallel RLC network in Fig. 2, S_{21} is as following [5].

$$|S_{21}|^2 = \frac{4Z_o^2[R^2(1-w^2LC)^2 + w^2L^2]}{4Z_o^2R^2(1-w^2LC)^2 + w^2L^2(R+2Z_o)^2} \quad (1)$$

The resistance, R can be obtained from S_{21} at the resonance frequency as

$$R = 2Z_o(\frac{1}{|S_{21}|} - 1)\Big|_{w=w_o} \quad (2)$$

The capacitance, C can also be by choosing the bandwidth ($w_2 - w_1$) with $S_{21} = a$ at $w = w_1 = w_2$,

$$C = \frac{\sqrt{a^2(R+2Z_o)^2 - 4Z_o^2}}{2Z_oR\sqrt{1-a^2}(w_2 - w_1)} \quad (3)$$

Then the inductance, L will be calculated by substituting C into the following equation,

$$L = (w_o^2C)^{-1} \quad (4)$$

III. MEASURED AND SIMULATED RESULTS

All structures in this paper are fabricated on a 45mm by 30mm substrate with ε_r of 2.33, a thickness of 31mil and the microstrip line on the slot has 50ohm characteristic impedance at 5GHz. The simulated results are obtained by using the three dimensional EM simulator, HFSS of Ansoft, and the measured results are obtained from an Agilent 8510C network analyzer. Fig. 4(a) shows the structure of the basic SGS. And the simulated and measured data for S21 and S11 characteristic of the basic SGS are compared in Fig. 4(b). When signals are transmitted from port1 to port 2 on microstrip line in the Split ground structure, the fundamental frequency at half effective wavelength equals to the slot length and its odd harmonics pass through the slot and radiate.

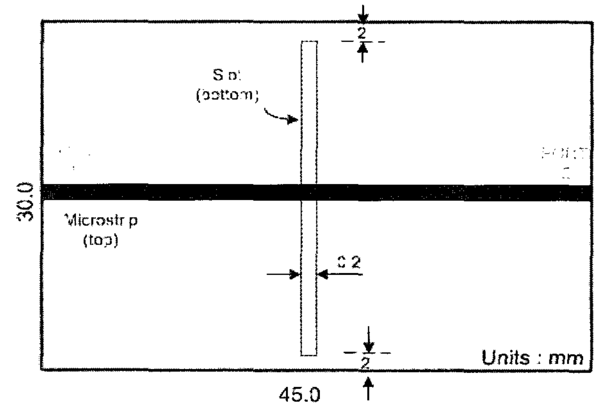

Fig. 4 (a) Structure and Dimension of Split ground structure (basic SGS)

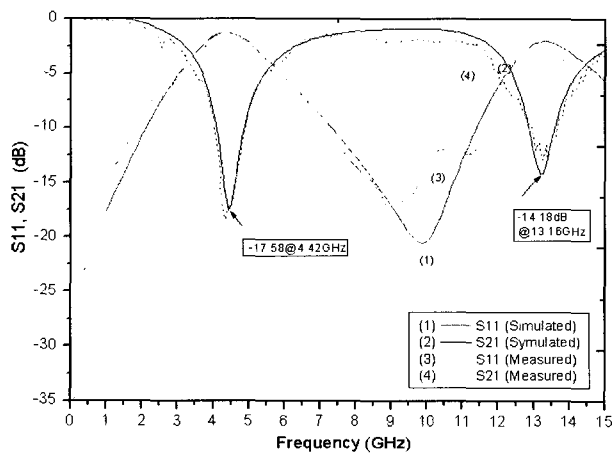

Fig. 4 (b) Transmission Characteristic of Split ground structure (basic SGS)

In Fig. 4(b), isolation for the fundamental frequency is 17.58dB at 4.42GHz and isolation for the third harmonic is 14.18dB at 13.16GHz. The isolation characteristic for the fundamental frequency can be used to increase isolation between digital circuit and analog/RF circuit, but odd mode harmonics give rise to radiation of unwanted electromagnetic field that may be EMI source. We modified the structure of slot to eliminate the third harmonic of frequency as Fig. 5(a), and we obtained an isolation of 28.37dB at the fundamental frequency 2.81GHz and could eliminate the harmonics as shown in Fig. 5(b). In this structure, the frequency of isolation was shifted lower because the effective inductance was increased. The structure of Fig. 5(a), Dumbbell shaped

SGS has better isolation characteristic than the basic SGS of Fig. 4(a) at the fundamental frequency. However, it also more increases radiation of EMI through the slot at the fundamental frequency. It is necessary to control the isolation characteristic depending on the interference noise level from digital signal. If the isolation is too much, the radiation gets higher at the lower frequency range.

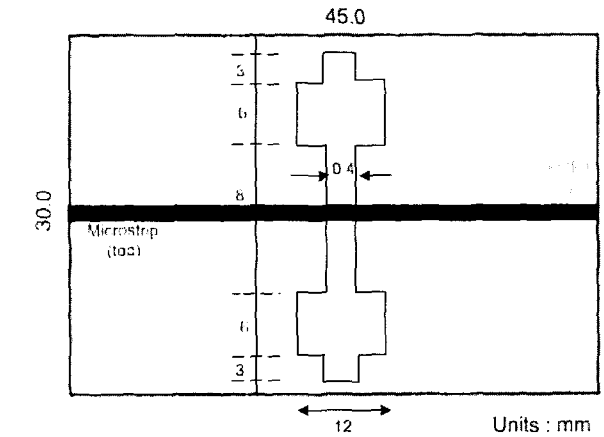

Fig. 5 (a) Structure and Dimension of Dumbbell shaped SGS

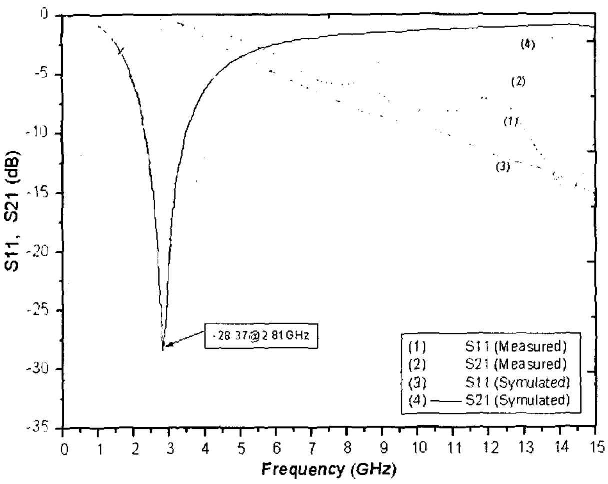

Fig. 5 (b) Characteristic of Dumbbell shaped SGS

As shown in above (2), when the Resistor (R) increases, the isolation (S21) will be decrease. So, We can control the isolation characteristic by adding the lumped resistor on the slot as shown in Fig. 6(a). Fig. 6(b) is the photograph for top and bottom view of Fig. 6(a). The isolation characteristic of Dumbbell shaped SGS adding the lumped resistor is represented in Fig. 6(c). When there is no resistor on the slot, the isolation is 28.37dB as in graph (1) of Fig. 6(c). In case of adding the 100Kohm resistor on the slot, the isolation characteristic is 21.3dB, decreased about 7dB. When the 1Kohm resistor is added on the slot, the isolation characteristic is 15.2dB and in case of 100ohm, the isolation characteristic is 5.4dB. Therefore, we can control the isolation characteristic by the resistor on the slot.

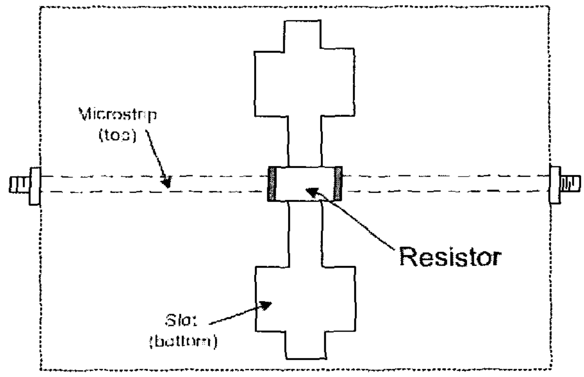

Fig. 6 (a) Dumbbell SGS with Resistor

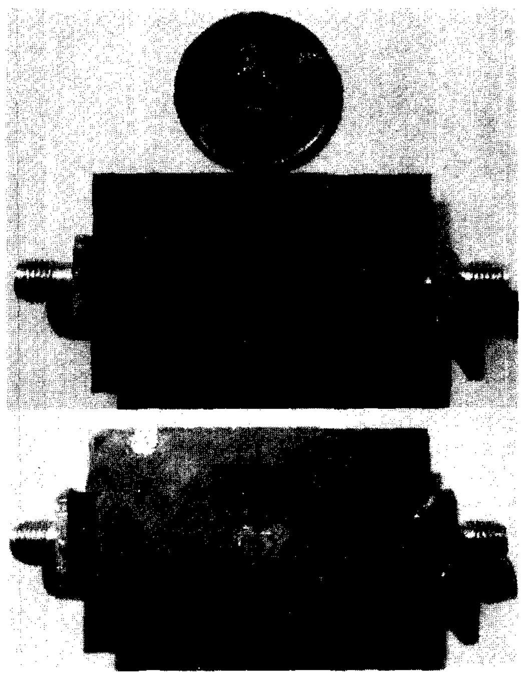

Fig. 6 (b) Photograph for bottom and top view of Dumbbell shaped SGS with Resistor

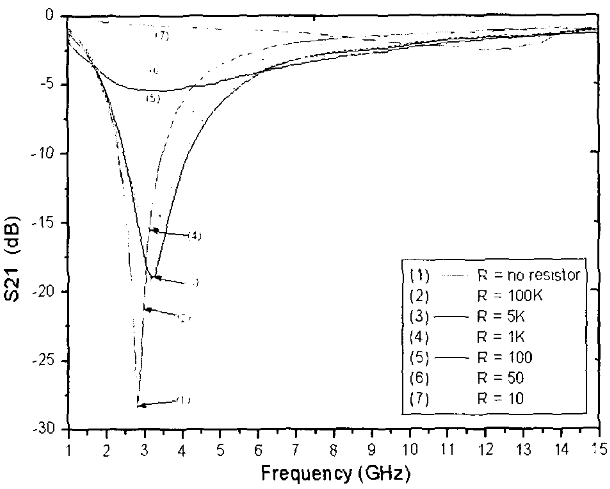

Fig. 6 (c) Characteristic of Dumbbell SGS with Resistor

The behavior of the SGS is like the slot antennas. When the isolation is increase, the radiation field from the slot is also increase.

The near field strength for the Split ground structure, Dumbbell shape SGS without a resistor and with a 100ohm resistor are compared by simulation using EM simulator in Fig. 7. For the basic SGS, there are more radiation at the low frequency nearby 4.4GHz and high frequency nearby 13.2GHz as in graph (1) of Fig. 7. For the Dumbbell shaped SGS, the radiation is decreased about 30*dBuV/m* at the high frequency comparing with the basic SGS as in graph (2) of Fig. 7. Also, using the Dumbbell shaped SGS with 100ohm resistor, the radiation is decreased more than 40*dBuV/m* at the high frequency and decreased more than 30*dBuV/m* at the low frequency than the basic SGS as shown in graph (3) in Fig. 7.

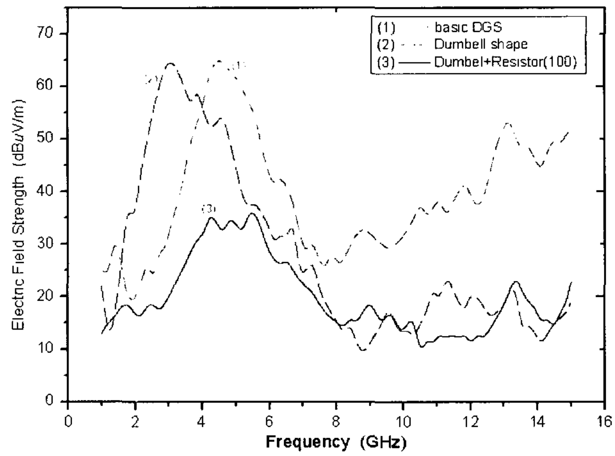

Fig. 7 Calculated Electric Field Strength (*dBuV/m*)

IV. CONCLUSION

The Split ground structure of Fig. 4(a) can be used to protect analog or RF signals from SSN interference of digital circuit, but it gives rise to undesired radiation. The electric field strength was about a 65 *dBuV/m* at 4.4GHz due to the fundamental frequency and about a 55 *dBuV/m* at frequency of 13.2GHz due to the third harmonic frequency as shown in graph (1) of Fig. 7. The proposed Dumbbell shaped SGS of Fig. 5(a) have reduced the radiation at the high frequency range compared with result of the basic SGS, the radiation is decreased about 30*dBuV/m* at the high frequency comparing with the basic SGS as in graph (2) of Fig. 7. But the electric field strength for low frequency range does not changed above a 65 *dBuV/m*. We have suppressed radiation above 30 *dBuV/m* for low frequency range using the 100ohm lumped resistor on the slot of the Dumbbell shaped SGS.

The results of this paper can be applied to the design of Printed Circuit Board that contain digital and analog /RF circuit in order to suppress the EMI and to have good isolation between circuits. Also, we can apply this approach to design of the variable attenuators for specific frequencies by using the result of Fig. 6.

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Received the B.S., M.S. in Electronic Engineering form the Sogang University, Seoul, Korea, in 1986, 1988, respectively. And received Ph. D. from Kyungnam University, Korea in 1999. From 1988 to 1993 he was a researcher in Communication Research Center of Samsung Electronics Co. Ltd. He developed RF and microwave systems such as VSAT and Cellular Base Station. From 1993 to 1999 he joined with Masan College as an assistant professor. He studied the crosstalk and interconnection problem on the multilayer PCB by using FDTD method. Since 1999, he has been on the faculty of Computer and Information Engineering Department at the Silla University, Busan, Korea. He was joined microwave Lab. of University of California, Los Angeles (UCLA) as Post-Doc. course from July 2002 to August 2003. His areas of interest are microwave integrated circuits, packaging technology, analysis of crosstalk and interconnection problem on the multilayer PCB.