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Broadband Substrate to Substrate Interconnection

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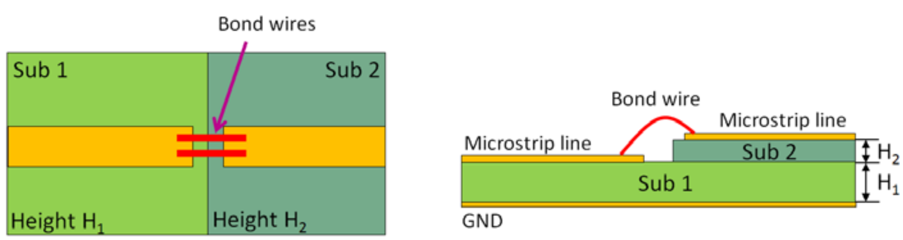
Abstract—A broadband substrate to substrate microwave circuit interconnection is proposed using bond wires and defected ground structure (DGS). The proposed square-shaped DGS etched under compensated microstrip open stubs not only expands its operating bandwidth, but also increases the characteristic impedance of microstrip line without narrowing its width, which breaks the PCB fabrication limitation of narrow stubs. The proposed structure can make the impedance of the microstrip line much larger than that without DGS. A 250 Ω characteristic impedance is easily achieved using 0.6 mm microstrip line with the proposed DGS. Measured S_{21} and S_{11} of the proposed interconnection are better than −0.3 and −15 dB from DC to 38 GHz, respectively. A bandwidth increment of more than 1200% is achieved compared with the conventional one.

1. INTRODUCTION

Bond wires are massively used in monolithic microwave integrated circuits (MMICs) and multi-chip modules (MCMs) for signal transmission among substrates with different heights, shown in Figure 1(a). Substrate 2 with a height of H_2 is stacked on Substrate 1 with a height of H_1, shown in Figure 1(b). Bond wires interconnections are used to interconnect Substrate 1 and Substrate 2.

Substrate to substrate interconnection is important on the following applications. First, for a higher isolation among transmitter, receiver and local oscillation (LO) parts of a transceiver, each part needs to be designed on a separated circuit substrate to avoid signal leakage through the shared substrate, especially the high power LO leakage to other parts. Secondly, not in every case it is possible to place all components on a circuit substrate but to place them on different circuit substrates for a complex circuit.



(a) (b)

Figure 1. Conventional substrate to substrate interconnection using single bond wire. (a) Top view and (b) side view.

Conventionally, substrate to substrate interconnection is established using bond wire, shown in Figure 1. However, a bond wire adds a low-pass element to the microwave system and limits its

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operating bandwidth. Approaches using multiple bond wires [1–5] or compensated microstrip stubs [6–11] can broaden the bandwidth of such interconnections, but none of them exceed 20 GHz frequencies. It is more important that compensated open stubs are used to broaden the bandwidth of bond wire interconnection in [4–7], but in most cases, the required compensated open stubs must be narrower than 0.1 mm, which is impossible to fabricate based on current printed circuit substrate (PCB) or low temperature co-fired ceramic (LTCC) fabrication process.

In this paper, a broadband interconnection using double bond wires with square-shaped DGS under open stubs has been proposed. The proposed square-shaped DGS etched under compensated microstrip open stubs not only expands its operating bandwidth, but also increases the characteristic impedance of microstrip line without narrowing its width, which breaks the PCB fabrication limitation of narrow stubs. One remarkable advantage of using the proposed structure is that it is possible to increase the characteristic impedance of microstrip line without narrowing its width. A 250 Ω characteristic impedance is easily achieved using 0.6 mm microstrip line with the proposed DGS patterned in the ground plane. The proposed interconnection also exhibits low-pass characteristics. The measured results agree well with the simulations.

2. BROADBAND INTERCONNECTION USING BOND WIRES WITH DGS

The top and side views of the proposed interconnection are shown in Figures 2(a) and (b), respectively. The heights of Substrate 1 and Substrate 2 are 0.5 mm and 0.2 mm, respectively. And its equivalent circuit is shown in Figure 3. Bond wire is equivalent to an inductor L that jeopardizes broadband application at microwave frequency. Compensation of the bond wire inductivity L can be achieved by further adding capacitance microstrip open stubs, whose resulting circuit resembles a three-element $(C_1 - L - C_2)$ low-pass structure, shown in Figure 3. After simulation with a full-wave EM-solver AXIEM [12], the highest cutoff frequency of the proposed structure (without DGS) can be achieved when the impedances of the two open stubs are both 250 Ω, which is equivalent to 0.04 mm width microstrip line on Rogers 4003C substrate with a dielectric constant of 3.38 and thickness of 0.508 mm. However, it is impossible to etch microstrip line thinner than 0.1 mm based on current PCB or LTCC fabrication process.

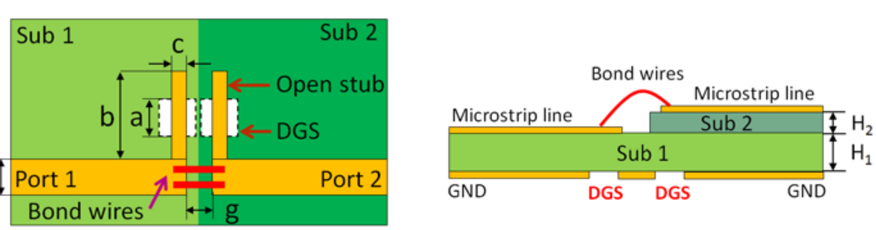
To solve the problem, we propose to etch square-shaped DGS under each open stub, which is helpful to achieve a higher impedance without narrowing width of open stubs. The equivalent circuit of the transmission line with the DGS can be simplified as shown in Figure 4(b). Then, using transmission line theory, impedance Z can be determined by Eqs. (1)–(4)

$$|S_{11}|\,(\text{dB}) = 20\log|\Gamma_{in}| \tag{1}$$

$$\Gamma_{in} = \frac{Z_{in} - Z_1}{Z_{in} + Z_1} \tag{2}$$

$$Z_{in} = \frac{Z^2}{Z_2}, \text{ at } \theta = \frac{\pi}{2} \tag{3}$$

$$Z^2 = Z_1 Z_2 \frac{1 + |\Gamma_{in}|}{1 - |\Gamma_{in}|}, \text{ at } \theta = \frac{\pi}{2} \tag{4}$$



(a) (b)

Figure 2. Structure of the proposed the broadband interconnection with DGS. (a) Top view and (b) side view.

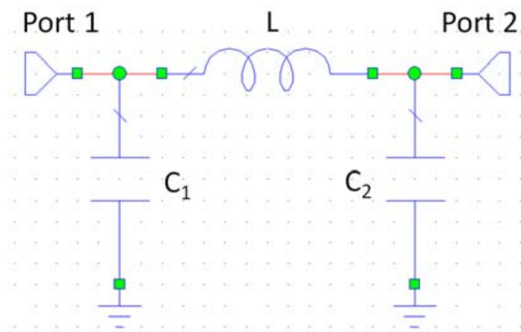
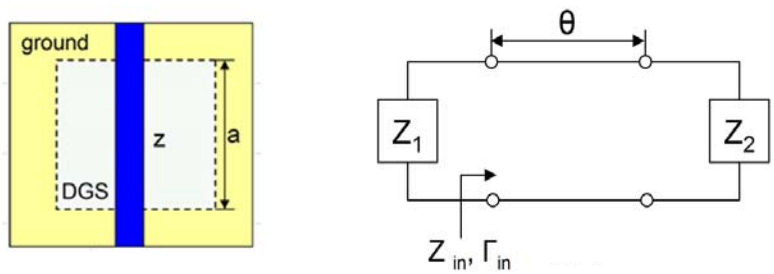


Figure 3. Equivalent circuit of the proposed interconnection.



(a) (b)

Figure 4. (a) Microstrip line with DGS and (b) simplified model for microstrip line with DGS.

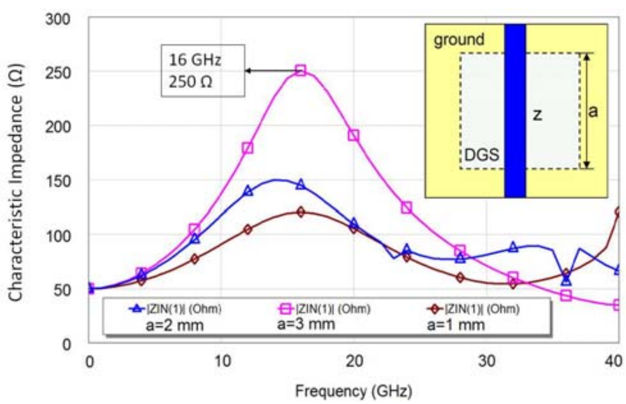


Figure 5. Characteristic impedance of microstrip line with DGS.

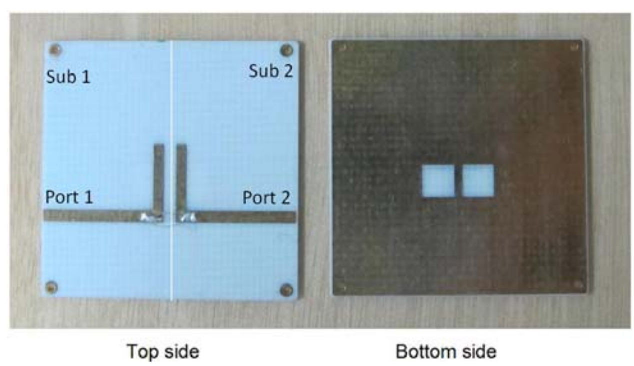
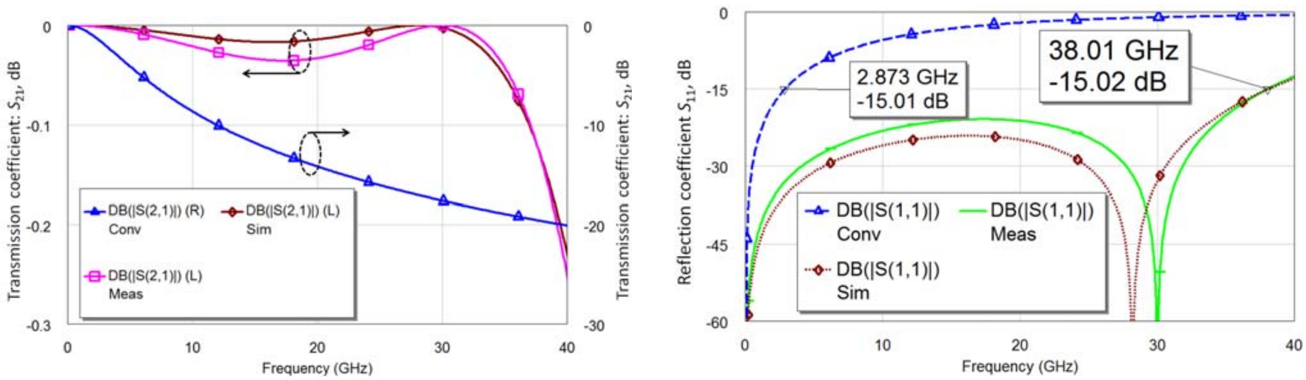


Figure 6. Photograph of the proposed interconnection.

When $\theta = \pi/2$, the maximum magnitude of the reflection coefficient Γ_{in} is achieved. Impedance value Z with different lengths of DGS is also simulated using full-wave EM-solver AXIEM, shown in Figures 4 and 5. Parameter "a" is the length of square-shaped DGS. We can see that impedances are 120 Ω (a = 1 mm), 150 Ω (a = 2 mm) and 250 Ω (a = 3 mm) at 16 GHz, respectively.

3. SIMULATED AND MEASURED RESULTS

EM-simulation was accomplished using AXIEM solver, which is a full-wave electromagnetic simulation software based on the method of moment (MoM). The optimized dimension parameters defined in Figure 2(a) are: $a = 3$ mm, $b = 3.6$ mm $c = 0.6$ mm, $g = 0.5$ mm and $w = 1.2$ mm. Equivalent circuit



(a) (b)

Figure 7. Simulated and measured S-parameters. (a) S_{21} and (b) S_{11}.

elements in Figure 3 are $C_1 = C_2 = 0.15\,\text{pf}$ and $L = 0.26\,\text{nH}$.

The top and bottom views of the proposed interconnection are shown in Figure 6. Measurements are carried out by Agilent N5230C network analyzer and Cascade Microtech Summit 9000 probe stations. Measured S_{21} and S_{11} of the proposed broadband interconnection are better than -0.3 and $-15\,\text{dB}$ from DC to 38 GHz, respectively. The simulated results agree well with the measured ones, shown in Figures 7(a) and (b). We also simulated the conventional interconnection using two bond wires for comparisons (see Figure 1). The bandwidth of the proposed interconnection is 38 GHz, whereas the bandwidth of conventional interconnection is only 2.837 GHz, shown in Figure 7(b). So the proposed structure provides more than 1200% bandwidth increment compared to a conventional one.

4. CONCLUSIONS

A novel structure of broadband substrate to substrate interconnection is proposed and implemented. The proposed square-shaped DGS etched under open stubs can increase the characteristic impedance of microstrip line without narrowing its width, which is helpful to expand its operating bandwidth and break the PCB fabrication limitation of narrow stubs. Measured S_{21} and S_{11} of the proposed interconnection are better than -0.3 and $-15\,\text{dB}$ from DC to 38 GHz, respectively. And a bandwidth increment of more than 1200% is achieved compared with the conventional one.

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